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BUILDING A BETTER WORLD

TECHNICAL MEMORANDUM

TO: Kelly Manheimer/USEPA **DATE:** January 19, 2011

COPY: Benny DeHghi/Honeywell

FROM: Sumani Al-Hassan, Craig Altare, and Don Walsh/MWH

SUBJECT: Groundwater Flow and Solute Transport Simulations to Evaluate Potential TCE Migration from the Bradley Landfill and Recycling Center, North Hollywood, California

1 Summary

In response to the U.S. Environmental Protection Agency's (USEPA) request for comments on the technical presentations made on August 26, 2010, MWH, on behalf of Honeywell, has evaluated potential trichloroethene (TCE) migration from the Bradley Landfill and Recycling Center (Landfill), North Hollywood, and presents USEPA the results of that evaluation in this Technical Memorandum. In particular, MWH modified USEPA's San Fernando Basin Feasibility Study, version B (SFBFS-B) groundwater flow model to incorporate the Verdugo Fault and ran simulations to evaluate the potential for such migration. ***Based on these simulations, it is reasonable to conclude that chemicals released at the Landfill migrate across the Verdugo Fault toward the Tuxford and Newberry landfills, and potentially migrate beyond the landfills in a southeasterly direction toward the Burbank-Glendale-Pasadena Airport.***

The simulations were conducted using a modified version of the San Fernando Valley (SFV) basinwide groundwater model. The model was modified to incorporate the Verdugo Fault. Additionally, the simulation period was extended back to water year 1969 and forward through water year 2009. Because of the addition of the fault, the flow model was re-calibrated locally in the area of the Landfill. Through calibration, the hydraulic conductance of the fault was estimated to be 7.5×10^{-4}/day and the hydraulic conductivity of Depth Region 1 in the area of the Landfill was set to a minimum of 75 ft/day. Sensitivity analyses were conducted on the hydraulic conductance of the fault and the hydraulic conductivity distribution of Depth Region 1 to evaluate their effects on the model results. Other sensitivity analyses conducted included increasing the partition coefficient of TCE and limiting the assumed TCE source area, concentration, and period of release in groundwater beneath the Landfill. The simulations were conducted using MODFLOW-SURFACT (version 3.0), the same program used by USEPA to run the original SFBFS-B model.

These simulations meet the objective of modifying and using the existing basinwide model to evaluate the potential for TCE originating from the Landfill to migrate in groundwater across the Verdugo Fault and into the remainder of the North Hollywood Operable Unit (NHOU). However, more precise calibration to water levels and TCE concentrations may be possible with additional effort.

The modified model will be further documented in a separate technical memorandum.

2 Introduction

The objective of the analysis presented in this technical memorandum is to evaluate the potential for TCE originating from the Landfill to migrate in groundwater southwest across the Verdugo Fault and then hydraulically down gradient into the remainder of the NHOU.

The SFBFS-B groundwater model was provided to MWH in 2007 by CH2M HILL on behalf of USEPA and is documented in the NHOU Focused Feasibility Study (FFS; CH2M HILL, 2009b). Modification of the model was necessary for the following reasons:

- The Landfill operated from 1959 to 2007, whereas input data for the SFBFS-B version of the model encompasses only water years 1982 to 2006 (e.g., water year 1982 extended from October 1981 to September 1982). It was therefore necessary to extend the simulation period to include years prior to 1982 in order to simulate times when initial potential releases from the Landfill occurred.
- The Landfill is located immediately northeast of the Verdugo Fault. Groundwater elevation data from monitoring wells on either side of the fault indicate a drop of over 100 feet of hydraulic head across the fault from the northeast to the southwest. This suggests that the fault may partially impede groundwater flow across it. Because of the potential influence of the fault on contaminant migration, and because the original model did not account for the fault, the model was modified to account for the fault.
- In the area of the Landfill, the spacing of rows in the original model was 1000 to 1750 feet. With this coarse spacing the Landfill occupied only three nodes. To more effectively model the area of the Landfill, the row spacing was decreased to 125 to 250 feet. The original 50-foot column spacing was retained because it was deemed adequate.
- The input files for the SFBFS-B model also were updated for 2007 to 2009.

This TM documents (1) how the modifications were made, (2) the re-calibration of the model in the area of the Landfill, and (3) the results of simulations conducted to evaluate the potential migration of TCE in groundwater.

3 Model Modification

3.1 Extension of Model Simulation Period

The input data for the SFBFS-B version of the model encompasses water years 1982 to 2006. The Landfill operated from 1959 to 2007. Although the Landfill started operations in 1959, the detailed pumping and recharge data needed to extend the simulation period back in time are only available beginning in October 1968. Therefore, the simulation period was extended back to water year 1969, which is judged adequate given the time necessary for chemicals to migrate through the vadose zone to groundwater.

MWH extended the simulation period back in time to October 1968 using pumping well and spreading basin data obtained from USEPA's SFV database (CH2M HILL, 2009a). Initial groundwater levels were digitized from a published map prepared by the ULARA Watermaster (California Department of Water Resources, 1970).

MWH also extended the simulation period forward to October 2009 using the following:

- Pumping well and spreading basin data obtained from USEPA's SFV database (CH2M HILL, 2009a).
- Draft pumping well and spreading basin data through July 2009 provided by the Los Angeles Department of Water and Power (LADWP).
- Pumping rates through September 2009 for the North Hollywood Aeration Wells provided by LADWP.
- Where needed, pumping well and spreading basin rates for August through October 2009 were assumed based on 2008 values.

The extended pumping record for six production wells in the immediate vicinity of the Landfill is presented in Figure 1. This figure indicates that total pumping from all six wells was generally greater than 1000 gallons per minute (gpm), and exceeded 2000 gpm at times during 1983 and 1997. However, there were also periods when total pumping was zero to only a few hundred gallons per minute. For example, it appears there was practically no pumping in 1994. In many other years such as in 1988, 1993 to 1995, 2006, and 2008, the total pumping from all the wells was less than 500 gpm.

3.2 Modification of Well Screen Elevations

During the process of extending the pumping record, discrepancies were detected between the screen elevations reported in the database and the screen elevations simulated by the SFBFS-B model for five pumping wells. As indicated in Table 1, we changed the screen elevations in the model to be consistent with the database. For Well 4916X, the screen elevations in the model could not be verified because corresponding values are not included in the database.

3.3 Modification of Injection at Spreading Basins

The original model uses both injection wells and areal recharge to represent spreading basin percolation. Because injection wells are node specific, and because a finer grid spacing was used in the modified model, recharge at all spreading basins was changed to areal recharge. Mathematically, this approach is no different than the injection well approach. In both the original and modified models, the potential splaying of recharge as it migrates through the vadose zone below the spreading basins is not accounted for (i.e., recharge is implicitly assumed to migrate vertically downward to the water table).

3.4 Incorporation of the Verdugo Fault

Figure 2 is a map showing the Verdugo fault as delineated by GIS data provided by the U.S. Geological Survey and the California Geological Survey (2010). The mapped fault location is corroborated by a sharp drop in groundwater elevation (greater than 100 feet) between monitoring wells 4916L and 4916C that has been attributed to the presence of the fault. The delineation of the fault could not be similarly corroborated at other locations, however.

4 Flow Model Calibration

The Verdugo Fault was incorporated into the model using the Horizontal Flow Barrier (HFB) package for MODFLOW (Hsieh and Freckleton, 1993). The HFB package represents the fault as a two-dimensional vertical plane, given that its width is negligible relative to the overall horizontal dimensions of the model. Using this package, the fault is hydraulically represented by a conductance term with units of 1/day, which is defined as the hydraulic conductivity of the barrier divided by its assumed, small width. Because there is no site specific data for the hydraulic conductance of the Verdugo Fault, it was estimated through model calibration. Historical water level data for calibrating the fault conductance is limited, however. The NHOU database contains groundwater elevation data for wells 4915, 4916A, and 4926 through the 1970s. However, wells 4916A and 4926 were both extracting groundwater during this period and therefore were not weighted strongly during calibration. Groundwater level data for several Bradley Landfill monitoring wells were obtained from the California State Water Resources Control Board's Geotracker website for 2005 to 2009.

Based on professional experience simulating faults at other sites in southern California, the initial hydraulic conductance of the fault was assumed to be 1×10^{-6}/day. Simulations with this value resulted in very high groundwater elevations up gradient of the fault and very high head differences across the fault. The calibration in the area of the Landfill was improved with a fault conductance of 7.5×10^{-4}/day (equivalent to a hydraulic conductivity of approximately 2.6×10^{-7} centimeters per second assuming an effective barrier width of 1 foot). Hydraulic conductivities in the Landfill area vary from 3 to 90 ft/day in the original SFBFS-B model. Areas of Depth Region 1 in the vicinity of the Verdugo fault with hydraulic conductivities less than 75 ft/day in the SFBFS-B version were increased to 75 ft/day for this calibration. Hydraulic conductivities in Depth Region 2 were not modified during the calibration process because no observed data (i.e., groundwater elevations) were available from wells screened in that zone.

Simulated groundwater contour maps for early 2008 and late 2009 are shown in Figures 3 and 4, respectively. Figure 3 shows simulated groundwater elevations when the Hansen spreading facility was percolating about 19,000 gpm of water to the aquifer and Figure 4 shows groundwater elevations when the Hansen facility was not percolating water. The figures indicate southeasterly groundwater flow almost parallel to the fault when there was discharge to the basin and a more southerly groundwater flow toward the fault when there was no discharge to the basin. The simulations indicate about 120 to 140 feet of head drop across the fault. Based on measured data for early 2008, the head drop across the fault was about 130 feet. Hydrographs of simulated and measured groundwater elevations at monitoring wells in the vicinity of the Landfill are presented in Figure 5. The figure shows reasonable agreement between the simulated and measured hydrographs. Because this exercise was a limited calibration involving only wells in the immediate vicinity of the Bradley Landfill, the calibration statistics were evaluated only for monitoring wells within one-half mile of the landfill. The root mean square error was estimated to be 43 feet.

We conducted a limited sensitivity analysis that included two alternative cases: 1) reducing the fault conductance one order of magnitude and 2) retaining the original hydraulic conductivity distribution of Depth Region 1. The results suggest that if the hydraulic conductance of the fault is reduced by one order of magnitude, groundwater elevations up gradient of the fault would rise substantially higher than the measured values and the head drop across the fault would increase to approximately 200 feet. For this case, the root mean square error increased from 43 to 86 feet. The measured and simulated hydrographs for this condition are presented in Figure 6.

The sensitivity analysis using the original hydraulic conductivity distribution, as shown in Figure 7, suggests that it reduces the accuracy of the calibration. The head drop across the fault becomes about 20 feet higher than the calibration shown in Figure 5, with the root mean square error increasing from 43 to 61 feet.

5 Capture Zone Simulation

The capture zone for a well is the volume of aquifer from which water flows to the pumping well during pumping. The shape of the capture zone is influenced by the pumping rate at the well and the properties of the aquifer surrounding it. The shape of the capture zone will vary through time with changing pumping rates at that well and in nearby wells.

Particle tracking simulations using MODPATH (Pollock, 1994) were used to evaluate capture zones for pumping wells in the Bradley area. Figure 8 shows capture zones as determined from forward particle tracking. For this simulation, a set of particles were released at the water-table surface at the beginning of the model period (i.e., October 1968) and tracked forward in time. The endpoint of each particle was used to determine which, if any, of the pumping wells captured the particle. The figure shows that the majority of the water captured by wells 4916, 4916A, 4916B, and 4926 originates at the Hansen spreading facility to the northwest. Only a small portion of the capture zones for wells 4916, 4916A, and 4916B intersect the area of the Bradley East landfill. The capture zone for well 4926, which pumped less groundwater than the three wells mentioned above (Figure 1), includes some of the Bradley East area when the well operates. Figure 9 shows capture zones for a reverse particle tracking scenario. For this simulation, particles were released near the boundaries of cells containing pumping wells and tracked backwards in time. The particles were released in October 1978, which was chosen because it was the last stress period that well 4926 pumped groundwater. The capture zones as determined by reverse particle tracking agree with those found using forward tracking. Both particle tracking methods indicate that pumping wells near the Bradley East landfill do not capture all of the groundwater from beneath the landfill. Well 4926 is the only well positioned in a suitable location to capture groundwater from beneath the landfill and it did not pump enough, both in terms of volume and duration (Figure 1), to ensure capture of potential contamination originating from Bradley East.

6 Solute Transport Simulation

After recalibration of the flow model with the Verdugo Fault incorporated, we conducted transport simulations to evaluate the potential migration of TCE from the Landfill. The transport simulations use an assumed concentration boundary condition at the Landfill and estimated values for several transport parameters. The following discusses how these were approximated in the model.

6.1 Boundary Conditions

Landfill leachate concentrations reaching groundwater typically vary with time depending on the distribution of contaminants within the vadose zone, changing recharge conditions, and other factors. Data needed to estimate the timing and rate of landfill leachate releases to groundwater are unavailable, and thus it is unknown when and at what concentrations landfill leachate reached the water table. Monitoring data indicate that TCE was detected in some downgradient Landfill monitoring wells as early as 1984. Based on this, it is reasonable to assume that leachate could have reached groundwater directly beneath the Landfill by October 1968, the start of the simulation period. Available information indicates that the Bradley East Landfill was unlined and did not have a leachate collection system, whereas the Bradley West Landfill does have a clay liner and a leachate collection system. Therefore, we assumed that the Bradley East Landfill is the likely point of release if a release occurred. Bradley East accepted waste from 1960 to the early 1980s.

As noted in the Solid Waste Assessment Test (SWAT) reports summarized by the Upper Los Angeles River Area (ULARA) Watermaster (1992), the Bradley West Landfill ponded with one half-million gallons of water in 1981-82. As discussed in Section 8, the limitations of the leachate collection system at this and other such times could account for observed TCE concentrations that are not simulated when the Bradley East Landfill is considered to be the only source.

Available data indicate that the maximum TCE concentration detected in Landfill area groundwater is 35 µg/L. This suggests that groundwater concentrations directly beneath the Landfill could range much higher. For modeling purposes, we assume a constant and uniformly distributed TCE concentration of 100 µg/L in the groundwater directly beneath the Bradley East Landfill from October 1968 to October 1984.

6.2 Transport Parameters

The migration of TCE in groundwater is influenced by the following primary fate and transport processes:

- Advection
- Hydrodynamic dispersion
- Sorption/desorption
- Chemical/biological transformations
- Immiscible flow

The sections below discuss each of these fate and transport processes and how they are incorporated into the model.

6.2.1 Advection

Advective transport refers to the movement of solutes due to the bulk flow of the fluid. It occurs through soil pores and fractures. The high hydraulic conductivity values estimated for the site suggest that groundwater velocities within the various aquifer layers are potentially significant. Consequently, advective transport was included in the model. Aquifer parameters affecting advective transport are hydraulic conductivity and the groundwater gradient. Advective flux is obtained from the flow model. Consequently, no additional parameters are required.

6.2.2 Hydrodynamic Dispersion

Hydrodynamic dispersion accounts for the lateral and vertical spreading of a contaminant plume beyond the area directly affected by advection, which in effect may lower peak concentrations. Hydrodynamic dispersion arises from two phenomena: molecular diffusion and mechanical dispersion. Molecular diffusion results from Brownian motion (i.e., intermolecular collisions causing solutes to move from regions of higher solute concentration to regions of lower solute concentration). The magnitude of molecular diffusion depends on the concentrations and chemical nature of the solute. Mechanical dispersion refers to the mechanical spread of the contaminant plume, and is caused by deviations in local pore velocities with respect to the average linear pore velocity. Hence, hydrodynamic dispersion always accompanies advective transport. The deviations from the average pore velocity are believed to be caused by heterogeneities in the aquifer.

Mechanical dispersion is dependent only on the properties of the porous medium. The effects of molecular diffusion and mechanical dispersion on contaminant transport cannot be easily separated in the field; thus, these processes have been conveniently characterized by a single coefficient, the hydrodynamic dispersion coefficient, in a mathematical form similar to Fick's first law of diffusion.

The hydrodynamic dispersion coefficient (D_h; L^2/T) can be approximated as the sum of its two components, the mechanical dispersion coefficient of the porous medium (D_l) and the molecular diffusion coefficient of the contaminant (D^*). Under typical groundwater flow velocities, the relative contribution of molecular diffusion is generally at least an order of magnitude less than that of mechanical dispersion. For this reason, the contribution of molecular diffusion to hydrodynamic dispersion is often neglected in groundwater flow models. Molecular diffusion was ignored in the simulations. Transport by molecular diffusion could however, be significant when groundwater velocities are very low.

The current geometry of the TCE plumes in groundwater suggests significant dispersion from the source areas over time. Thus, the dispersion process was included in the model, in order to completely describe the observed transport behavior.

In groundwater flow modeling, the dispersion coefficient is often estimated using a characteristic length referred to as the dispersivity. However, quantification of dispersion is complicated by the so-called "scale effect" where the dispersivity seems to increase as the contaminant plume moves down gradient. Gelhar et al. (1992) examined many plumes and related longitudinal dispersivity (a) to plume length (X). Longitudinal dispersivity is frequently reported as 10 percent of the plume length, but tends to become constant for longer plumes (e.g., plumes greater than 3,000 feet). Xu and Eckstein (1995) fit a curve to the longitudinal dispersivity data presented by Gelhar et al. (1992), which was later modified slightly by Al-Suwaiyan (1996), as expressed in the following equation (in meters):

$$a = 0.82\,(\log_{10}X)^{2.446}$$

Transverse dispersivity is typically assumed to equal about 10 to 30 percent of longitudinal dispersivity whereas vertical dispersivity is typically assumed to equal 0.01 to 10 percent of longitudinal dispersivity. Because the extent of the TCE plume from the Landfill is unknown, it was conservatively assumed that dispersion is low with a longitudinal dispersivity of 5 feet, transverse dispersivity of 2 feet and vertical dispersivity of 0.05 feet. Based on the above equation, this corresponds to a plume length of about 65 feet. The assumption of a low dispersivity value was used to limit the spread of the plume across the fault to mainly advective processes.

6.2.3 Sorption/Desorption

Sorption accounts for the distribution of a contaminant between dissolved and sorbed phases. Under linear equilibrium conditions, a distribution coefficient is used to relate the dissolved- and sorbed-phase concentrations. The sorption process is complex and is influenced by physical and mineralogical properties of the solid media and the chemistry, temperature, and pressure of the groundwater (USEPA, 1998). For a given mass of contaminant in an aquifer, the fraction of the mass available for advective and dispersive transport is strongly influenced by the sorptive capacity of the aquifer matrix. The sorption process tends to reduce the impact of advective and dispersive transport by limiting the amount of dissolved contaminant available for transport.

In groundwater models, the effect of sorption is typically accounted for by a retardation factor (R_f) that defines the motion of a dissolved contaminant relative to the average pore water velocity. A retardation factor of 1.0 implies sorption does not impact the transport of the solute being considered, such that the solute travels at the same rate as groundwater. A retardation factor greater than 1.0 indicates that the rate of solute movement will be slow (i.e., retarded) relative to groundwater flow. The magnitude of retardation is inversely proportional to the value of the retardation factor. The retardation factor is operationally defined as:

$$R_f = 1 + \frac{\rho_b}{\eta} \cdot K_d$$

where:

$$K_d = K_{oc} \cdot f_{oc}$$

and:

ρ_b = bulk density of soil matrix (M/L^3)
K_d = distribution coefficient (L^3/M)
K_{oc} = partition coefficient (L^3/M)
f_{oc} = organic carbon fraction (dimensionless)
R_f = retardation factor (dimensionless)
η = effective porosity (dimensionless)

The impact of sorption was accounted for by calculating a distribution coefficient and resulting retardation factor representative of TCE transport in area groundwater. In arid environments, the fraction of organic carbon in soil is usually below 0.1 percent. Under such conditions, USEPA's Soil Screening Guidance manual (1996) provides an alternative estimate for the distribution coefficient. According to the guidance document, the distribution coefficient may be approximated by the following equation:

$$\log K_d = 1.01 \log (K_{ow}) - 3.46$$

where K_{ow} is the octanol/water partition coefficient of the contaminant. The above equation is valid for log K_{ow} values less than 3.7. Estimated K_d values using this equation can be a factor of 2 to 3 times higher or lower than actual values of K_d for nonpolar sorbates. Using the above equation and TCE K_{ow} values reported in the literature of 2.38 to 2.71 (USEPA, 1986; 1996), the distribution coefficient for TCE is estimated to range from 0.09 to 0.19 ml/g. Based on this range, we assumed a TCE partition coefficient of 0.1 ml/g. Using typical values of bulk density (1.6 g/cm^3) and effective porosity (0.25), the simulated TCE retardation factor is 1.6.

6.2.4 Chemical/Biological Transformations

Biodegradation and transformation are processes that reduce contaminant concentrations by changing the form in which the individual chemical components exist. Chemical transformations with the potential to significantly affect the fate of TCE are photo-oxidation and abiotic dechlorination in the presence of iron minerals and other catalysts (Howard, 1990). Because light energy for photo-oxidation is unavailable in the subsurface, this reaction is not expected to play a major role in the fate and transport of TCE within the NHOU aquifer system. With respect to biological transformations, TCE readily degrades under anaerobic conditions, however it does not easily degrade under aerobic conditions (Howard, 1990). Because TCE transformation byproducts have not been detected at concentrations indicative of significant degradation, we have assumed that biological degradation is negligible.

6.2.5 Immiscible Phase Flow

Dense nonaqueous phase liquids (DNAPLs) such as TCE are immiscible fluids with a density greater than water. Because groundwater TCE concentrations in the vicinity of the landfill are low relative to the solubility of TCE, the presence of DNAPLs is not likely. Consequently, immiscible flow was ignored.

6.2.6 Initial TCE Distribution

To simulate the potential migration of TCE from the Landfill, we assumed that the initial concentration of TCE was zero everywhere except immediately beneath landfill.

7 Base Case Simulation

Figure 10 presents the simulated distribution of TCE concentrations in Depth Region 1 groundwater after 41 years of transport (October 1968 through September 2009), assuming the transport parameters described above and a continuous source of 100 µg/L from immediately beneath the Bradley East Landfill between October 1968 and October 1984. These results suggest that TCE would migrate southeast across the Verdugo Fault and extend down gradient beyond the Tuxford and Newberry landfills. . Under the assumed source conditions, TCE in Depth Region 2 would extend south to the vicinity of Lockheed Plant C1 at concentrations in excess of the regulated maximum contaminant level (MCL) of 5 µg/L (Figure 11).

The simulations indicate that the TCE plume in Depth Region 1 will detach from the source area under the assumed source duration described above. Such plume detachment may not be realistic where residual TCE mass remains in the vadose zone and/or is retarded within low-conductivity heterogeneities not reflected in the model. The simulated TCE plume in Depth Region 2 does not completely detach from the source area by September

2009 because of an area of relatively low hydraulic conductivity that occurs in the original model along the model boundary northeast of the Verdugo fault (Figure 11).

Figure 12 presents time-concentration plots comparing simulated and observed TCE concentrations at monitoring wells 4916C, 4916H, and 4916J. Under the base case assumptions, the simulated magnitude of TCE concentrations at these wells is consistent with the range of observed concentrations. However, for wells 4916H and 4916J, the observed occurrence of peak concentrations occurs 10 or more years later than the simulated peak concentrations. By refining the TCE source area and duration, the fifth alternate case described in Section 8 achieves a closer fit between observed and simulated peak concentrations.

For well 4916C, observed detections of TCE are not simulated by the model (Figure 12). This suggests that an unmodeled source occurs hydraulically up gradient of this well. As shown in Figure 2 and subsequent figures, this well is located approximately down gradient of the Bradley West Landfill. As described in Section 6.1, the Bradley West Landfill experienced significant ponding during wet water year 1981-82 (ULARA Watermaster, 1992), and may have released contaminants to groundwater under such conditions.

8 Sensitivity Analyses

We simulated TCE transport for the two alternate cases discussed in Section 4 and three additional cases described here. These five scenarios differ from the base case as follows:

- Reduced Fault Conductivity - The conductance of the Verdugo Fault is reduced by one order of magnitude to 7.5×10^{-5}/day. These results are presented in Figures 13 and 14.
- Original Horizontal Conductivity - The Depth Region 1 distribution of hydraulic conductivity along the Verdugo Fault is retained from the original SFBFS-B model (Figures 15 and 16).
- High Distribution Coefficient - The TCE partition coefficient could vary by a factor of 2 to 3 compared to the estimated representative value of 0.1 mL/g, and thus range from about 0.03 to 0.3 mL/g (Section 6.2.3). In light of this, we conducted a sensitivity analysis assuming a partition coefficient of 0.18 mL/g, equal to about two times the estimated representative value, which increased the retardation factor to 2.2 (Figures 17 and 18).
- Reduced Source Concentration –The constant TCE concentration boundary at the Landfill was reduced from 100 µg/L to 50 µg/L and retained the high retardation factor (no figures are provided for this scenario).
- Limited Release – The magnitude of concentrations simulated for the base case is consistent with the range of TCE concentrations observed in down gradient monitoring wells (Figure 12). To demonstrate a better fit with the timing of observed peak TCE concentrations, we limited the source area to the southern tip of the Landfill and limited the release period to 1988-1991 (Figures 19, 20, and 21).

The results of the five alternate transport simulations suggest the following:

- If the hydraulic conductance of the Verdugo Fault is one order of magnitude less than the calibrated value, it is still likely that TCE would cross the Verdugo Fault and migrate toward the Tuxford and Newberry landfills (Figures 13 and 14).
- If the hydraulic conductivity along the fault in Depth Region 1 remains the same as in the original model, and the hydraulic conductance of the Verdugo Fault remains at the value calibrated for the modified model, the simulations suggest TCE would still likely cross the Verdugo Fault and migrate toward the Tuxford and Newberry landfills (Figures 15 and 16).
- If the assumed partition coefficient of TCE is increased to 0.18 ml/g, TCE would likely cross the Verdugo Fault. However, for the assumed base-case source condition, the down gradient extent of concentrations at or above the MCL would remain up gradient of the Tuxford and Newberry landfills (Figures 17 and 18).
- If the constant concentration boundary at the Landfill is reduced to 50 µg/L and the partition coefficient is increased to 0.18 ml/g, the simulations suggest that TCE could still cross the Verdugo Fault but extend only as far as the Tuxford and Newberry landfills (no figures are provided for this scenario).
- If the TCE source area is limited to the southern tip of the Landfill during 1988 to 1991, a better fit can be achieved between the timing of simulated and observed peak concentrations (Figures 19, 20, and 21).

9 Conclusions

Based on these simulations, it is reasonable to conclude that chemicals released at the Landfill migrate across the Verdugo Fault toward the Tuxford and Newberry landfills, and potentially migrate beyond the landfills in a southeasterly direction toward the Burbank-Glendale-Pasadena Airport.

This technical memorandum meets the objective of modifying and using the existing basinwide model to evaluate the potential for TCE originating from the Landfill to migrate in groundwater across the Verdugo Fault and into the remainder of the NHOU. However, more precise calibration to water levels and TCE concentrations may be possible with additional effort.

10 References

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Attachments: Figures 1 through 21 and Table 1.

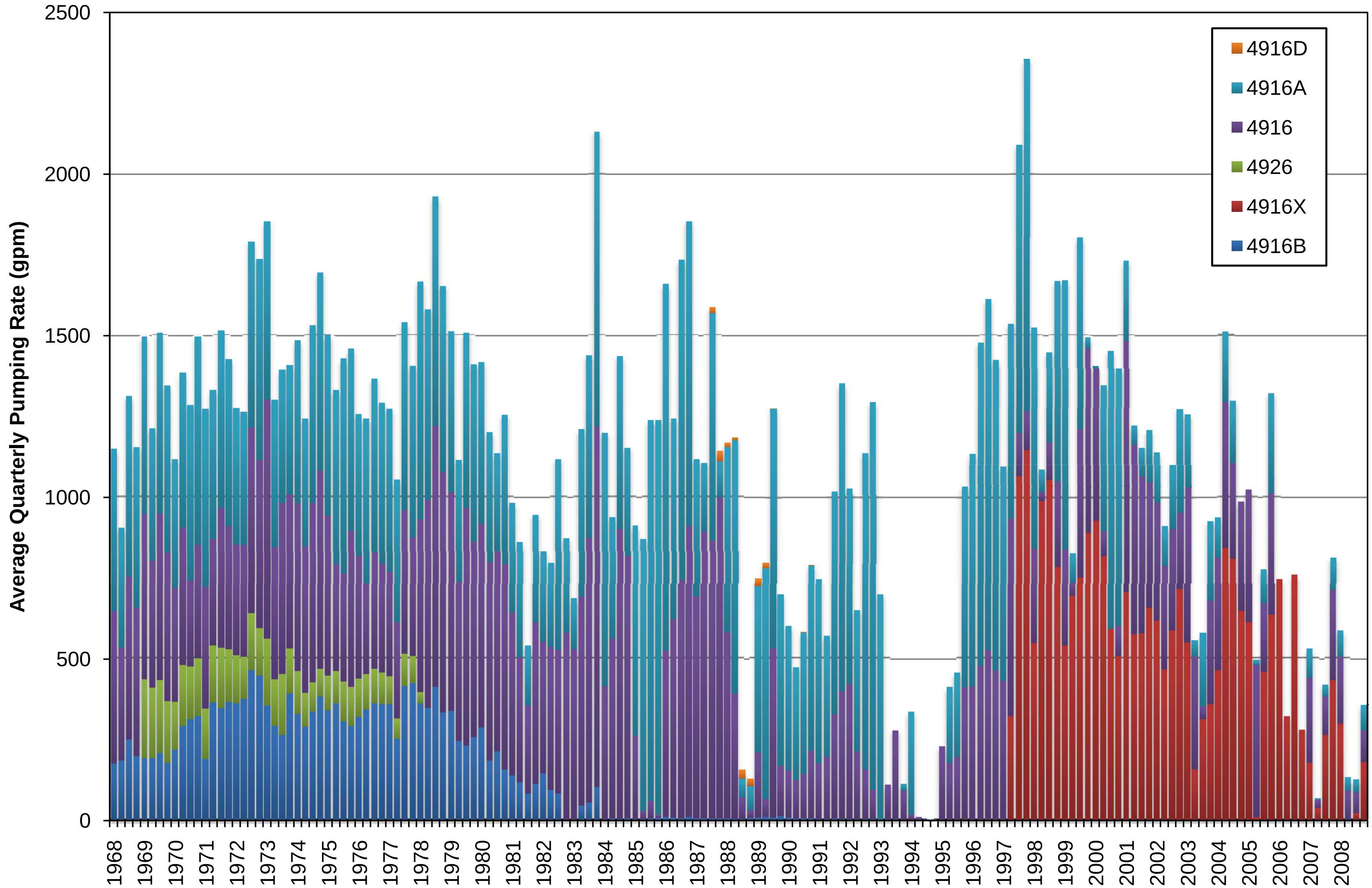
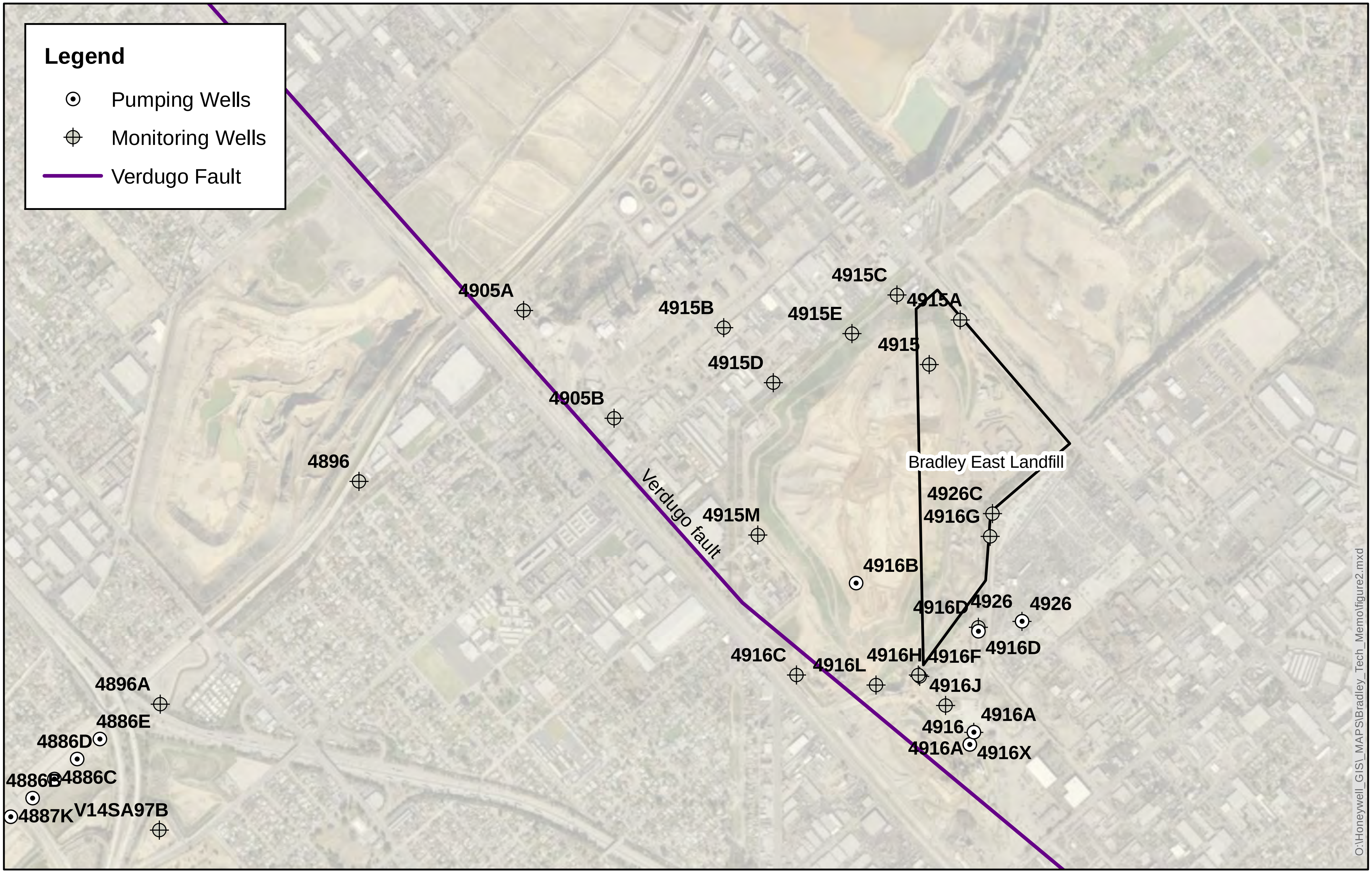


FIGURE 1

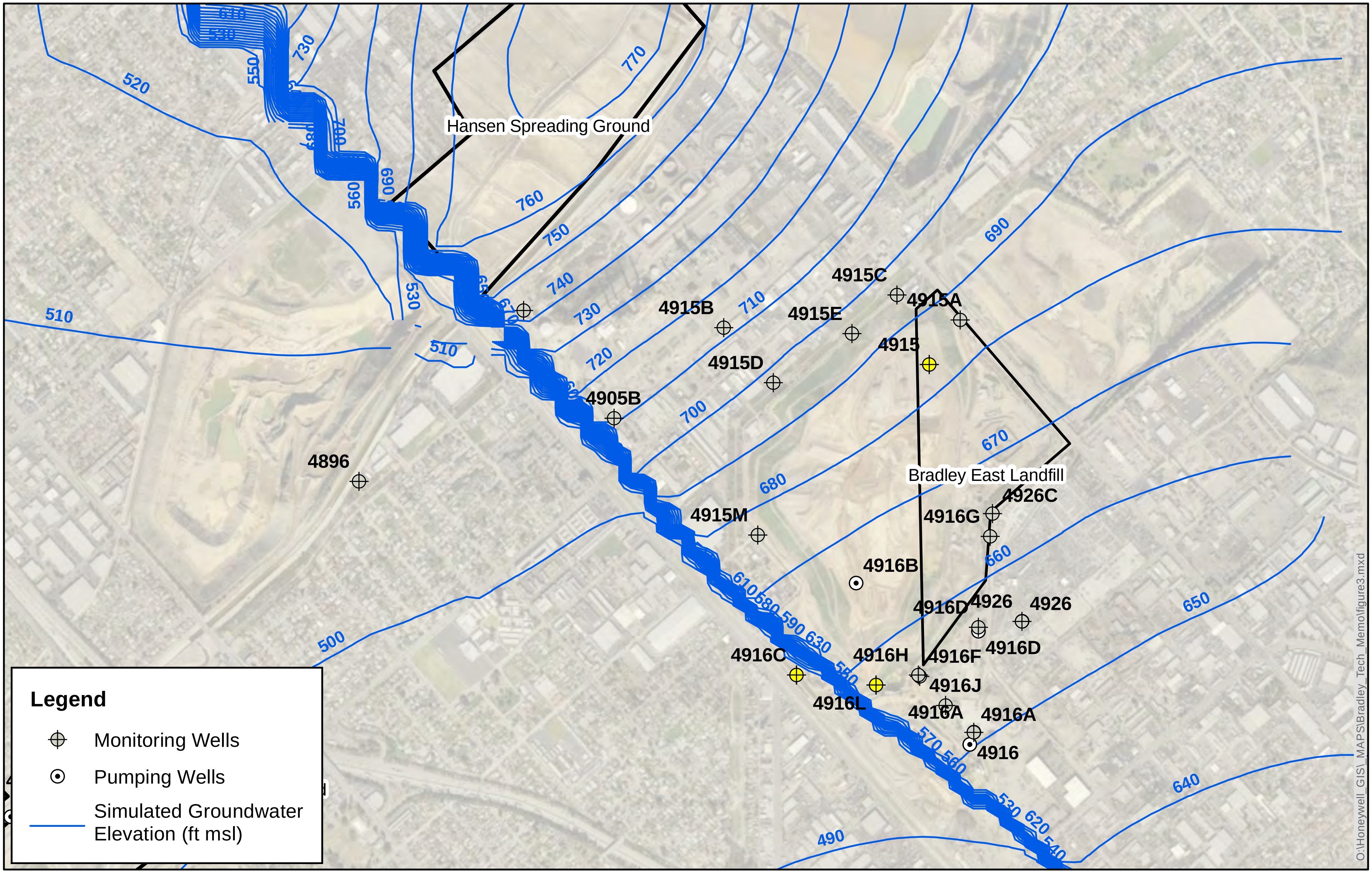
HISTORICAL PUMPING IN THE BRADLEY LANDFILL AREA



Note:
Fault data obtained from:
U.S. Geological Survey and California Geological Survey, 2010,
Quaternary fault and fold database for the United States, accessed
Nov 1, 2010, from USGS web site: http//earthquake.usgs.gov/regional/qfaults/.

FIGURE 2

Location of Verdugo Fault in
Vicinity of Bradley Landfill



Note:
Simulated groundwater elevation from model layer one for average pumping conditions during the period from January to March, 2008

Hansen spreading ground recharged 7,438 acre-feet during this period

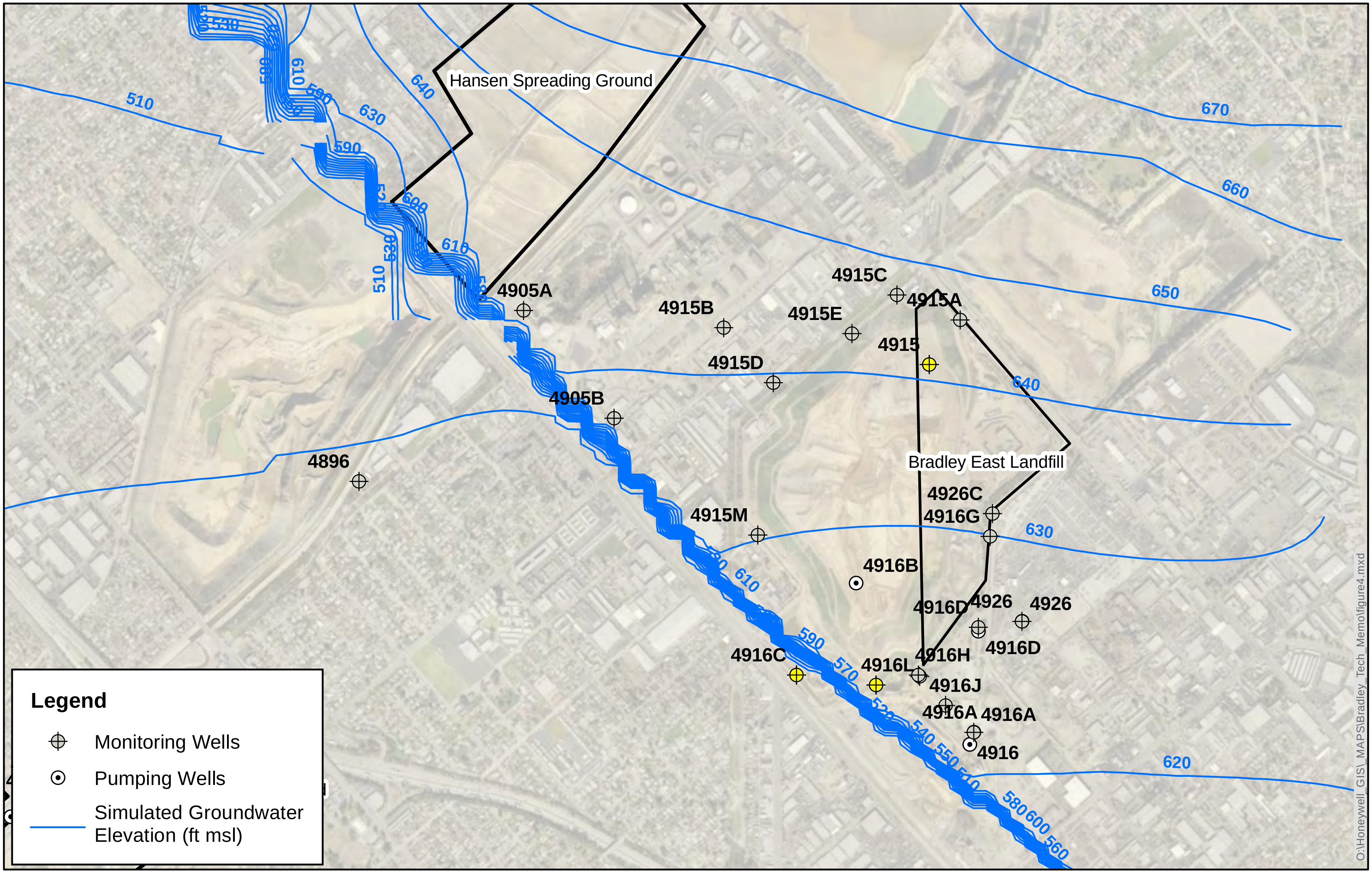
Hydrographs for monitoring wells with yellow symbols are shown on Figures 5 - 7

N

0 700 1,400 2,800 Feet

FIGURE 3

Simulated Groundwater Elevations
January to March 2008



Note:
Simulated groundwater elevation from model layer one for average pumping conditions during the period from January to March, 2008

Hansen spreading ground did not operate during this period

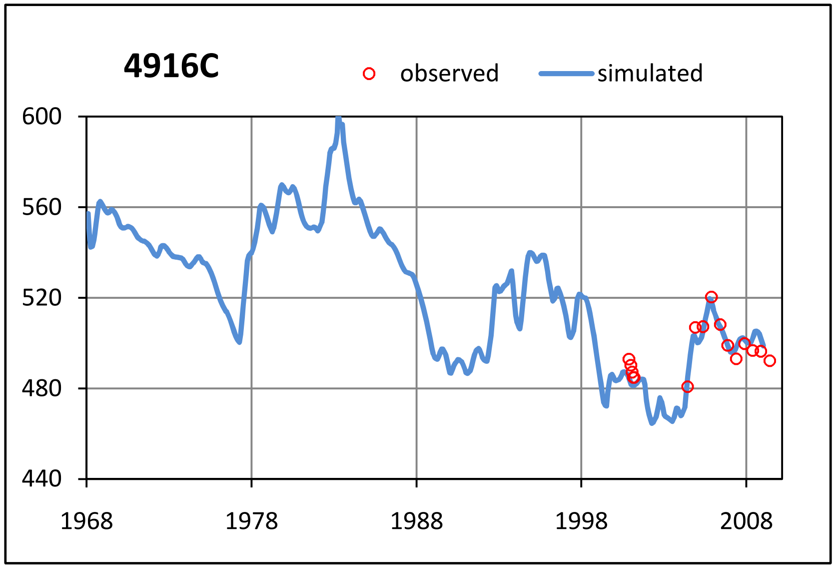
Hydrographs for monitoring wells with yellow symbols are shown on Figures 5 - 7

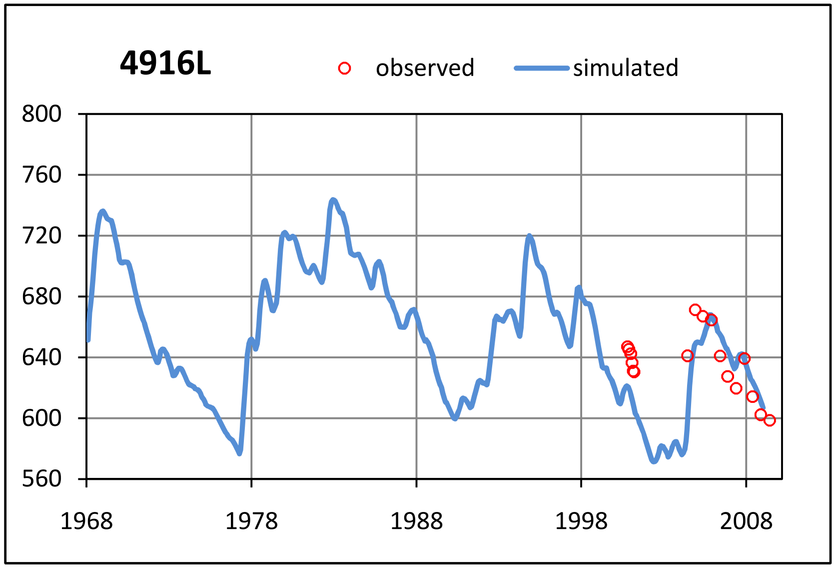
N

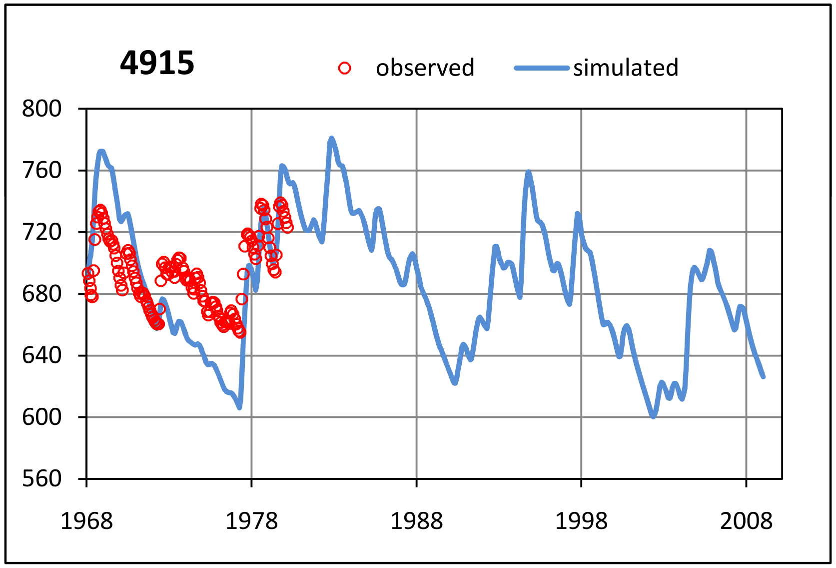
0 700 1,400 2,800 Feet

FIGURE 4

Simulated Groundwater Elevations
July to October 2009



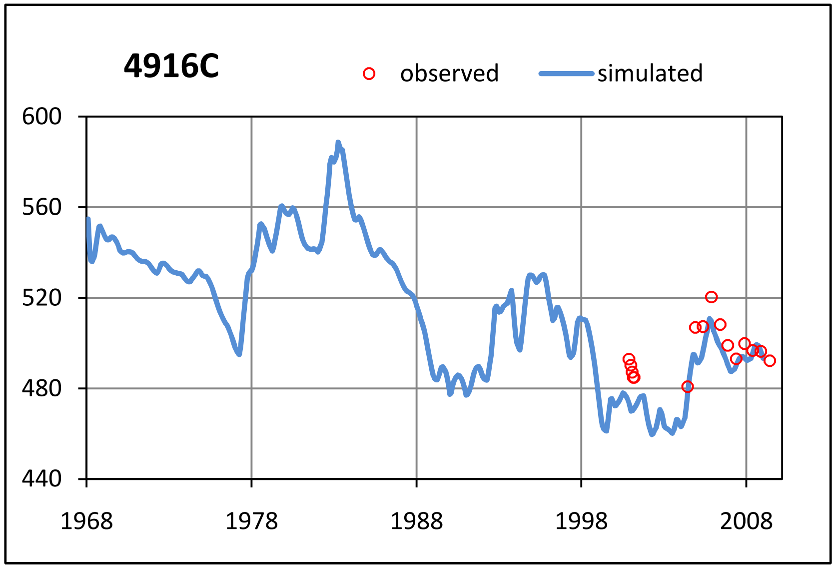


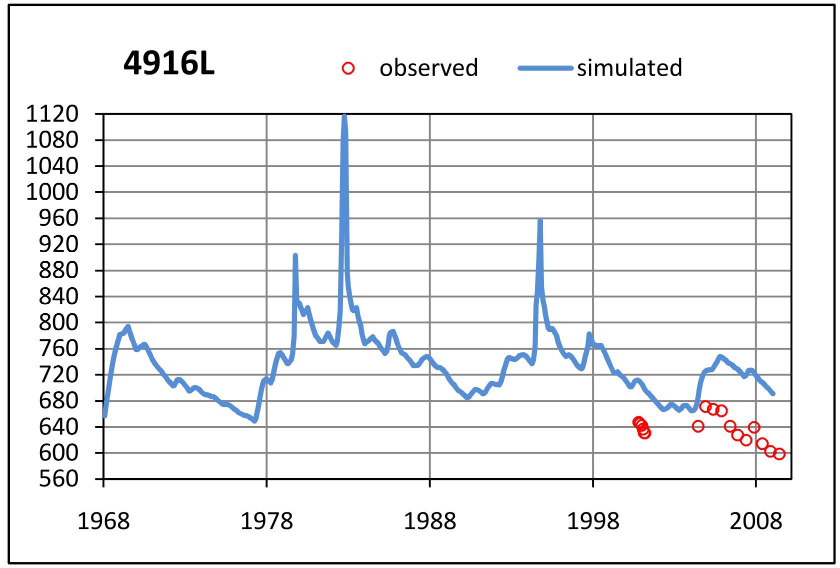


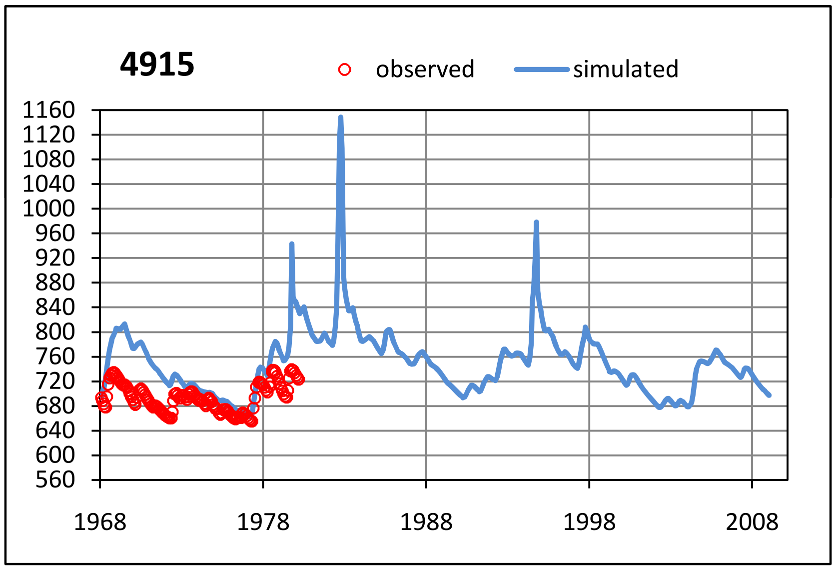
Note: Simulated groundwater elevations reported from layer 1 of the groundwater model. Monitoring well 4916C is screened across model layers 1 and 2 but the differences between water levels in each layer are not perceptible at this scale.

FIGURE 5

Simulated and Observed Hydrographs - Calibration Scenario



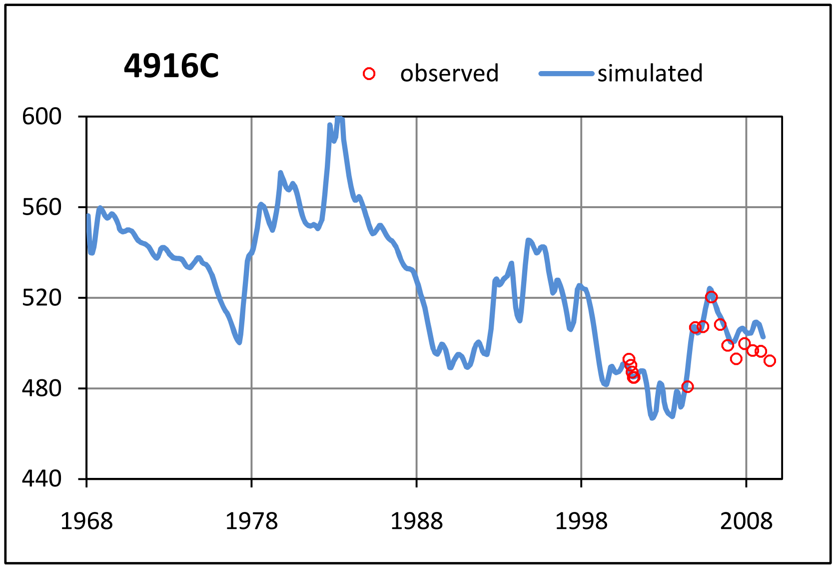


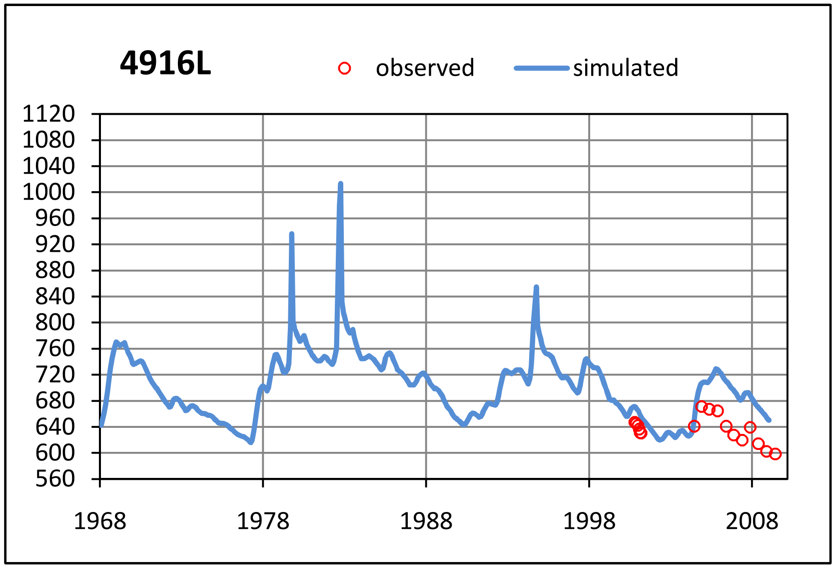


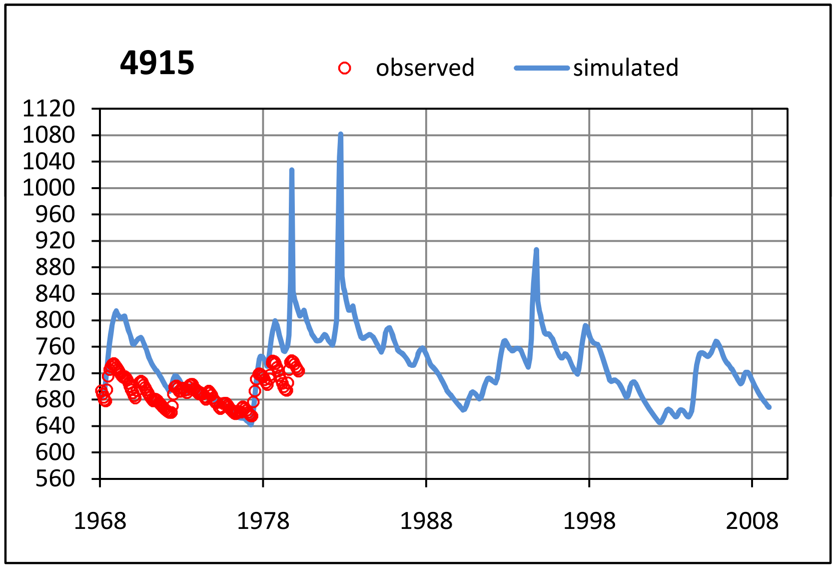
Note: Simulated groundwater elevations reported from layer 1 of the groundwater model. Monitoring well 4916C is screened across model layers 1 and 2 but the differences between water levels in each layer are not perceptible at this scale.

FIGURE 6

Simulated and Observed Hydrographs - Reduced Verdugo Fault Conductivity Scenario



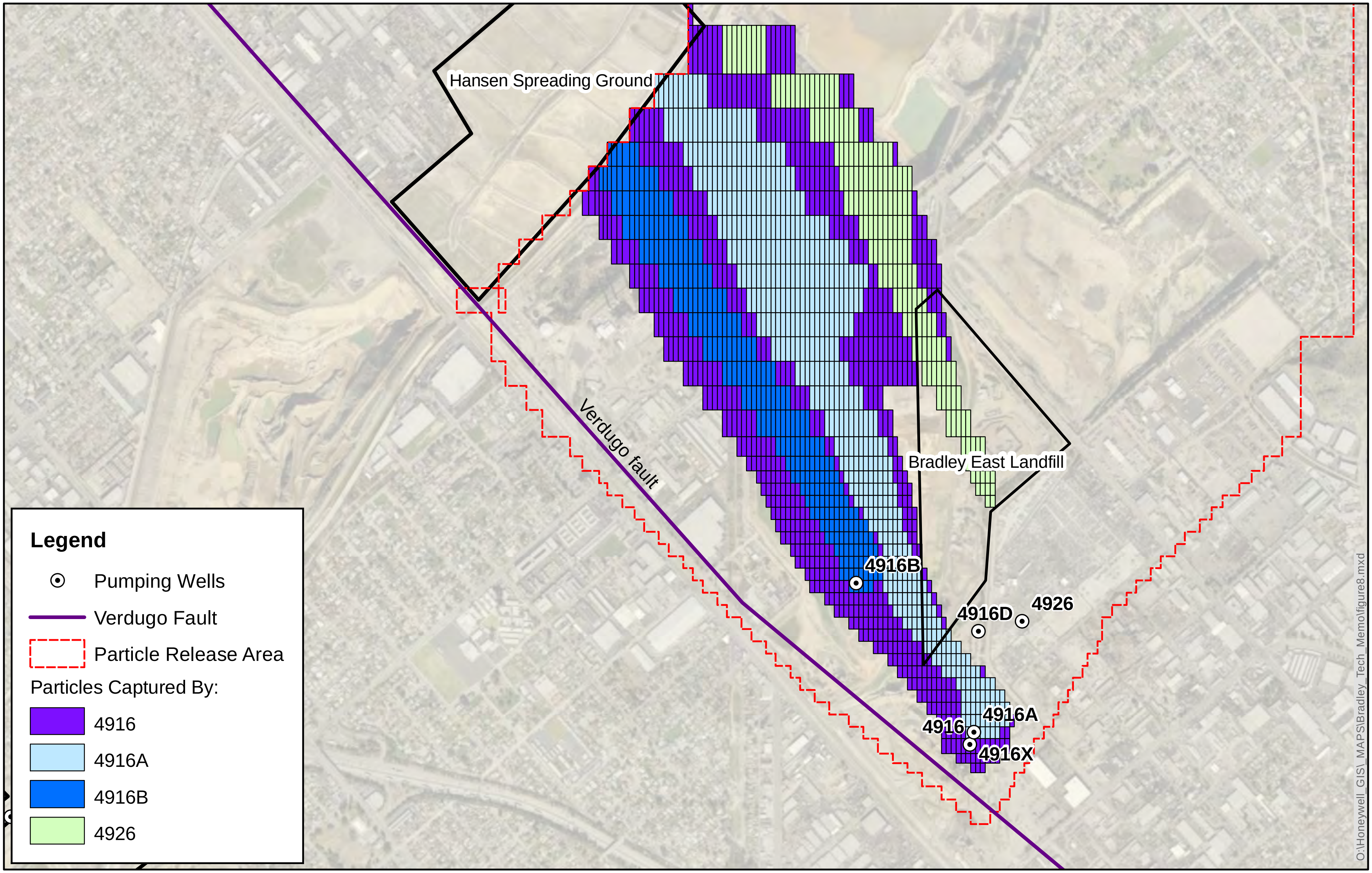




Note: Simulated groundwater elevations reported from layer 1 of the groundwater model. Monitoring well 4916C is screened across model layers 1 and 2 but the differences between water levels in each layer are not perceptible at this scale.

FIGURE 7

Simulated and Observed Hydrographs - Original Conductivity Scenario



Note:
Simulated particles released from the water table surface at each model cell within the red polygon. Particles were tracked forward in time from the beginning of the simulation (October 1968). Shading is assigned based on the pumping well capturing the particle.

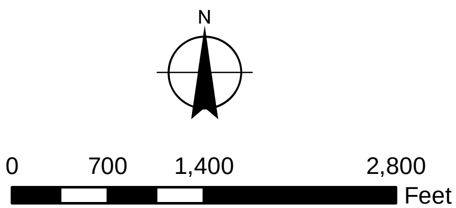
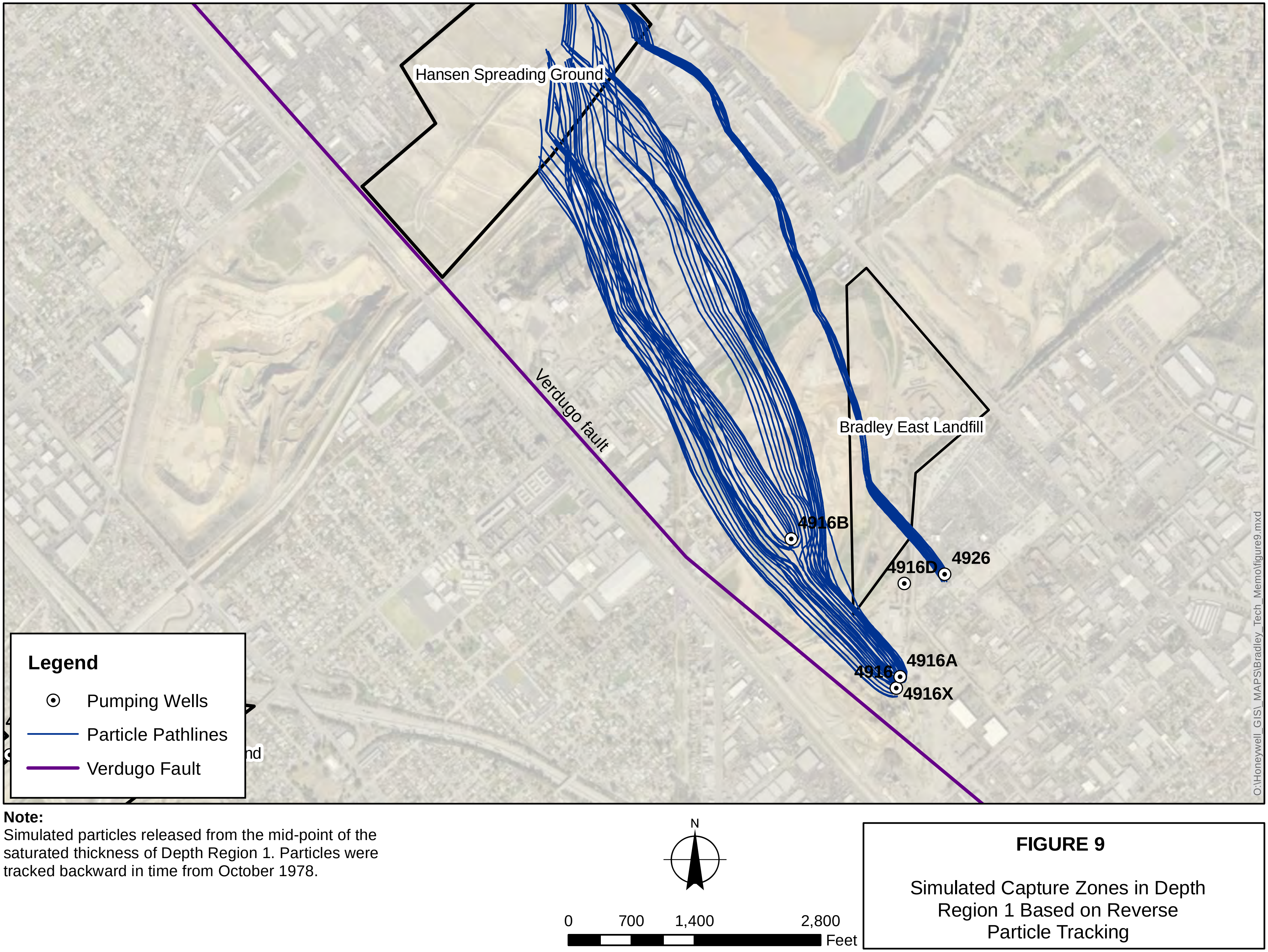


FIGURE 8

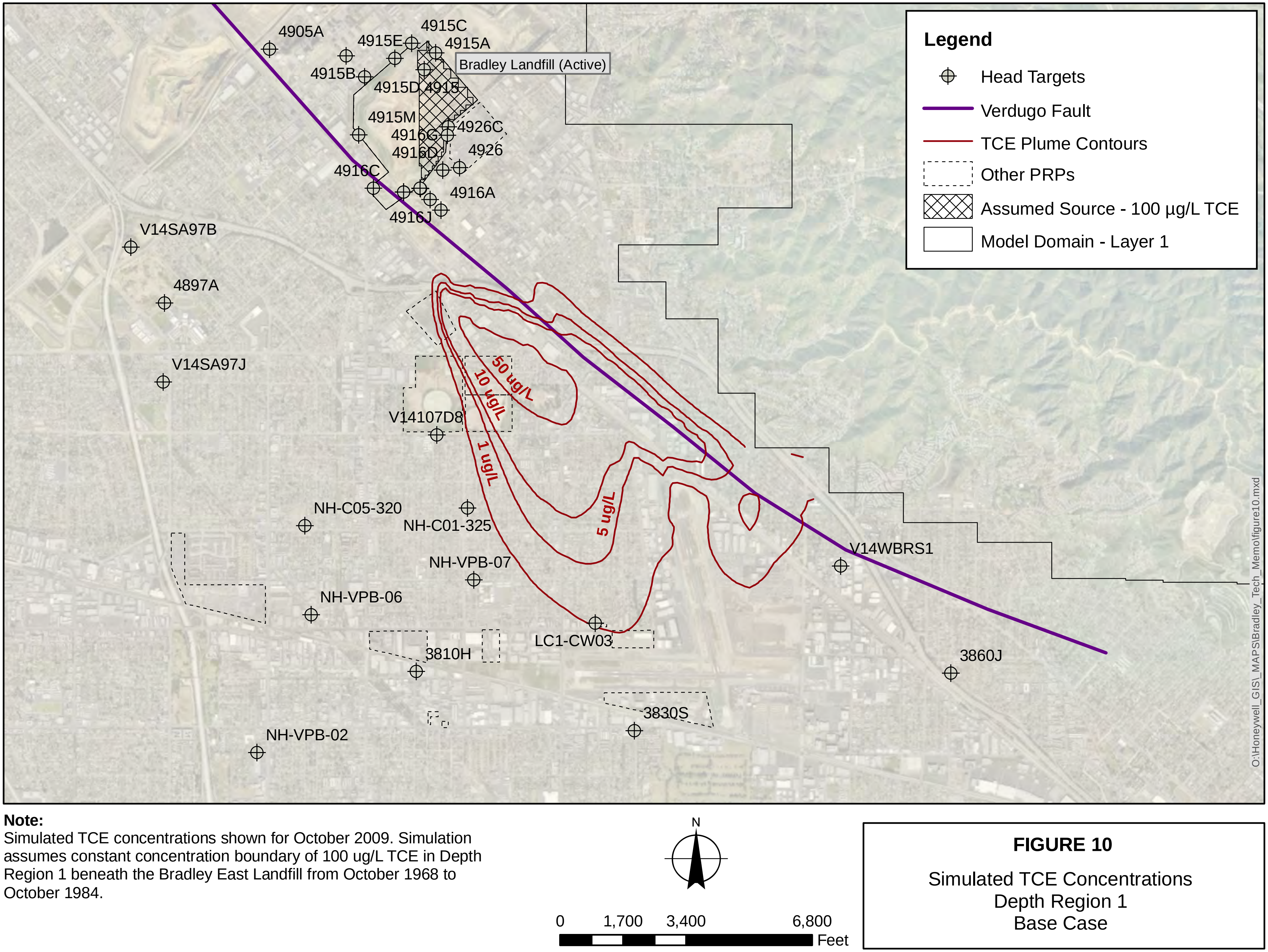
Simulated Capture Zones Based on Forward Particle Tracking; Particles Released October 1968



Note:
Simulated particles released from the mid-point of the saturated thickness of Depth Region 1. Particles were tracked backward in time from October 1978.

FIGURE 9

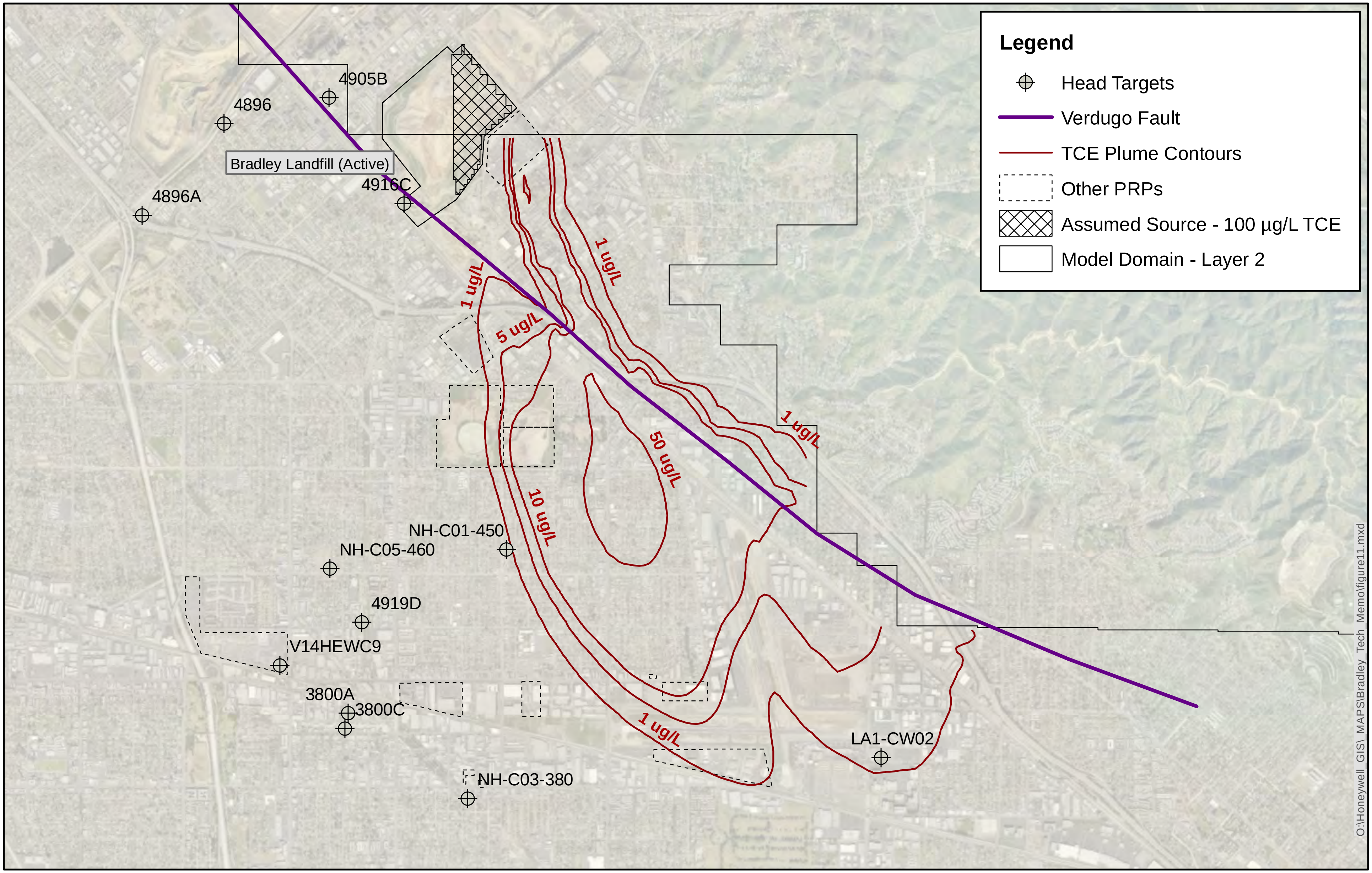
Simulated Capture Zones in Depth Region 1 Based on Reverse Particle Tracking



Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1968 to October 1984.

FIGURE 10

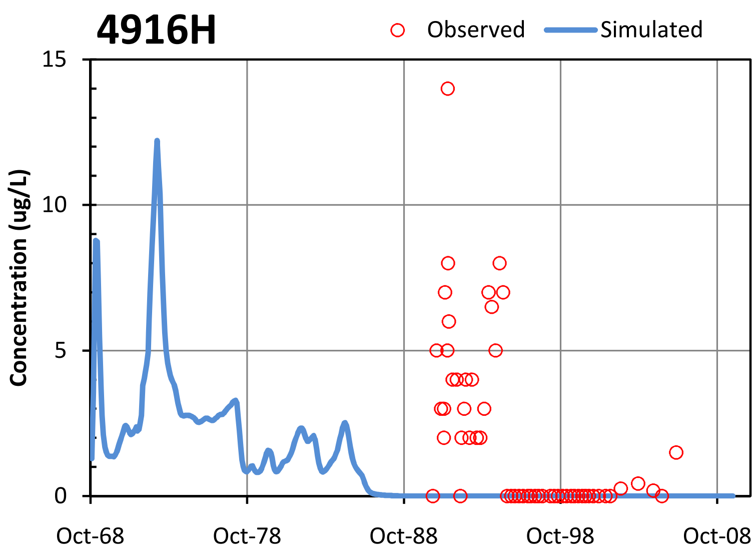
Simulated TCE Concentrations
Depth Region 1
Base Case

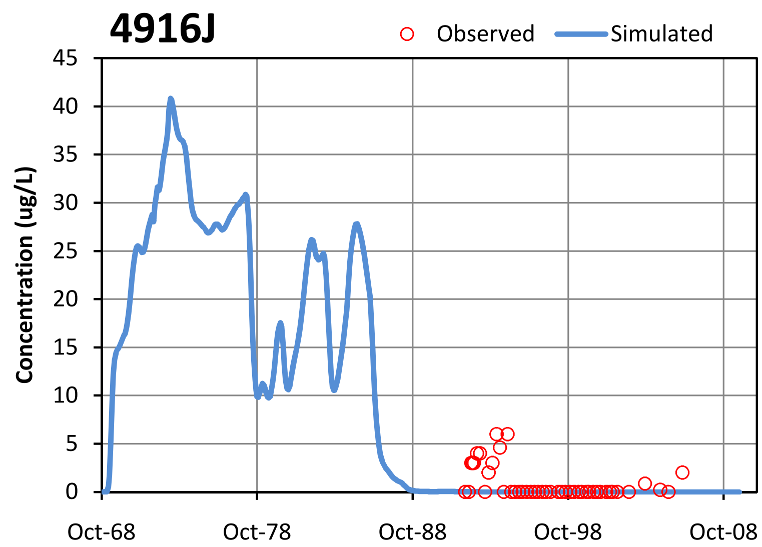


Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1968 to October 1984.

FIGURE 11

Simulated TCE Concentrations
Depth Region 2
Base Case





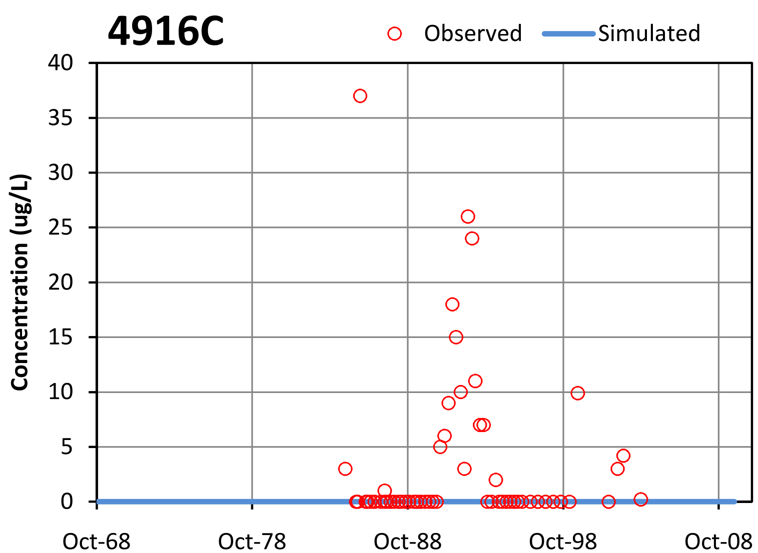
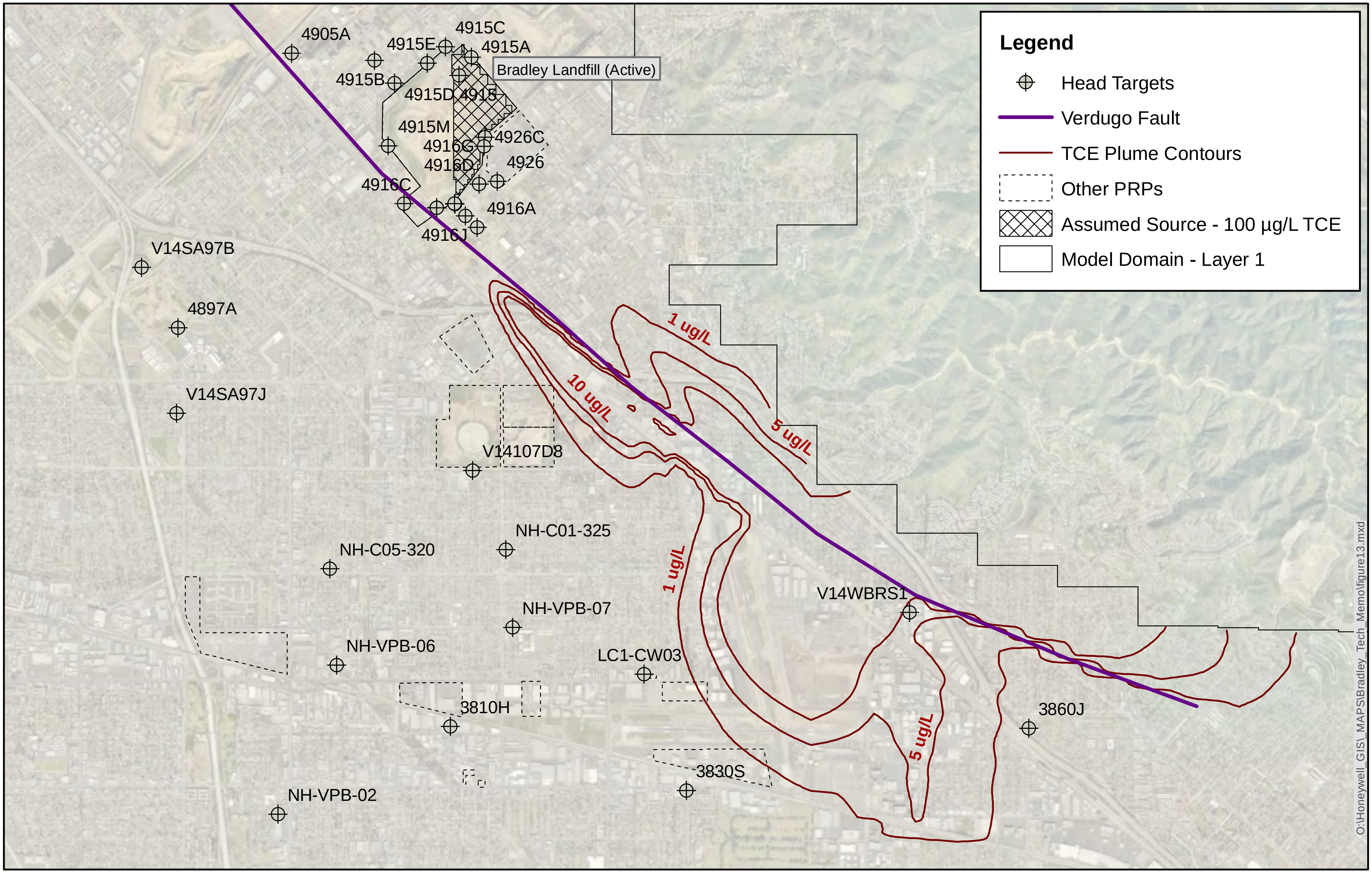


FIGURE 12

Simulated and Observed TCE Concentrations - Base Case



Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1968 to October 1984.

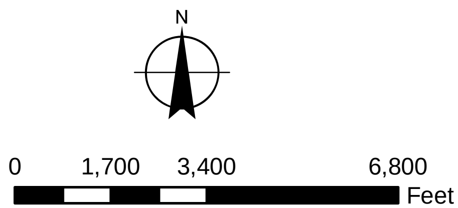
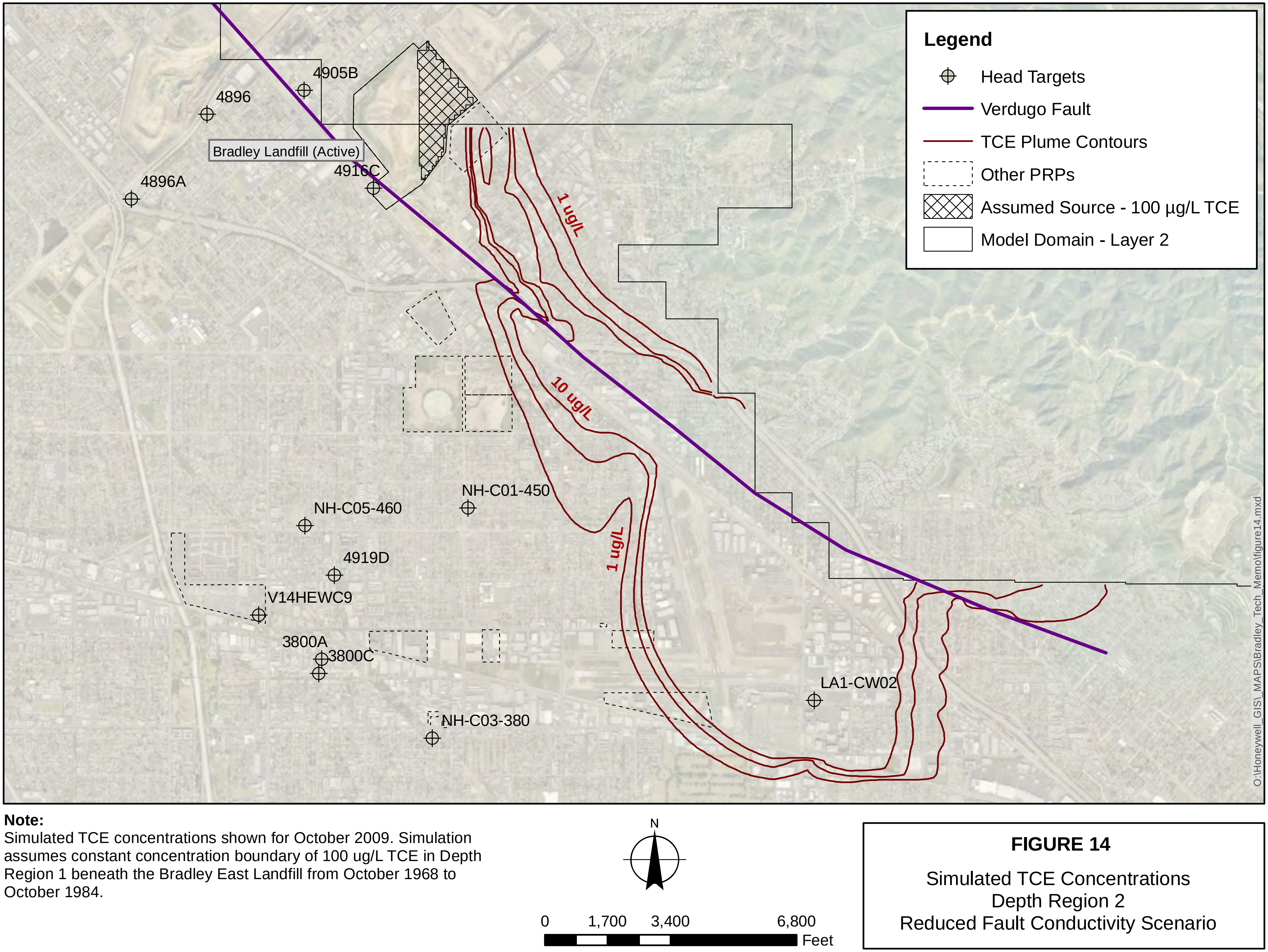


FIGURE 13

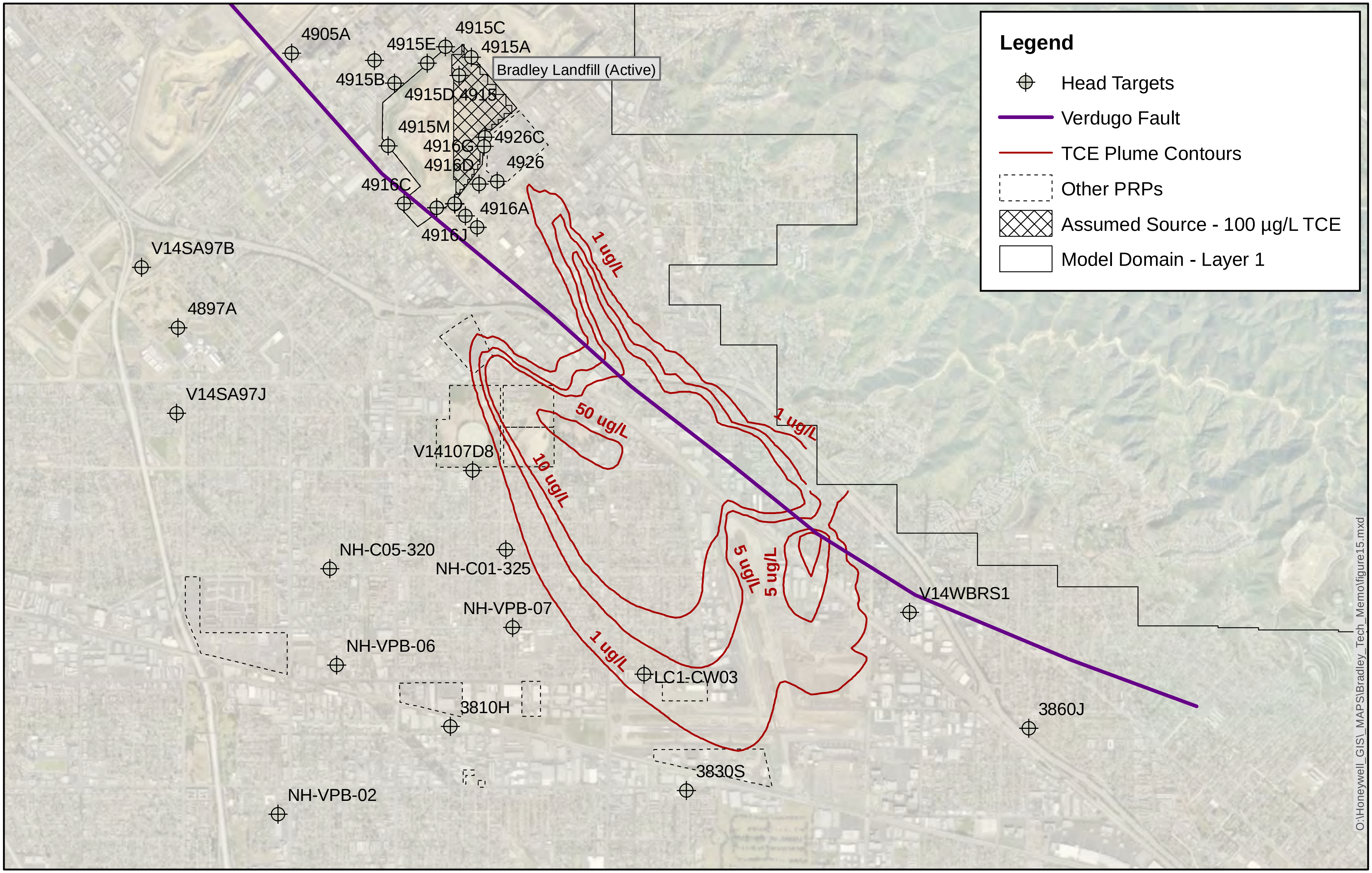
Simulated TCE Concentrations
Depth Region 1
Reduced Fault Conductivity Scenario



Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1968 to October 1984.

FIGURE 14

Simulated TCE Concentrations
Depth Region 2
Reduced Fault Conductivity Scenario



Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1968 to October 1984.

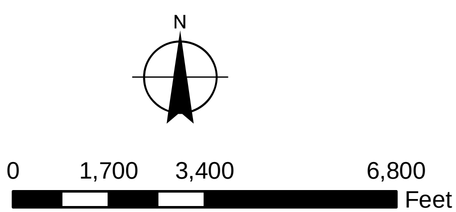
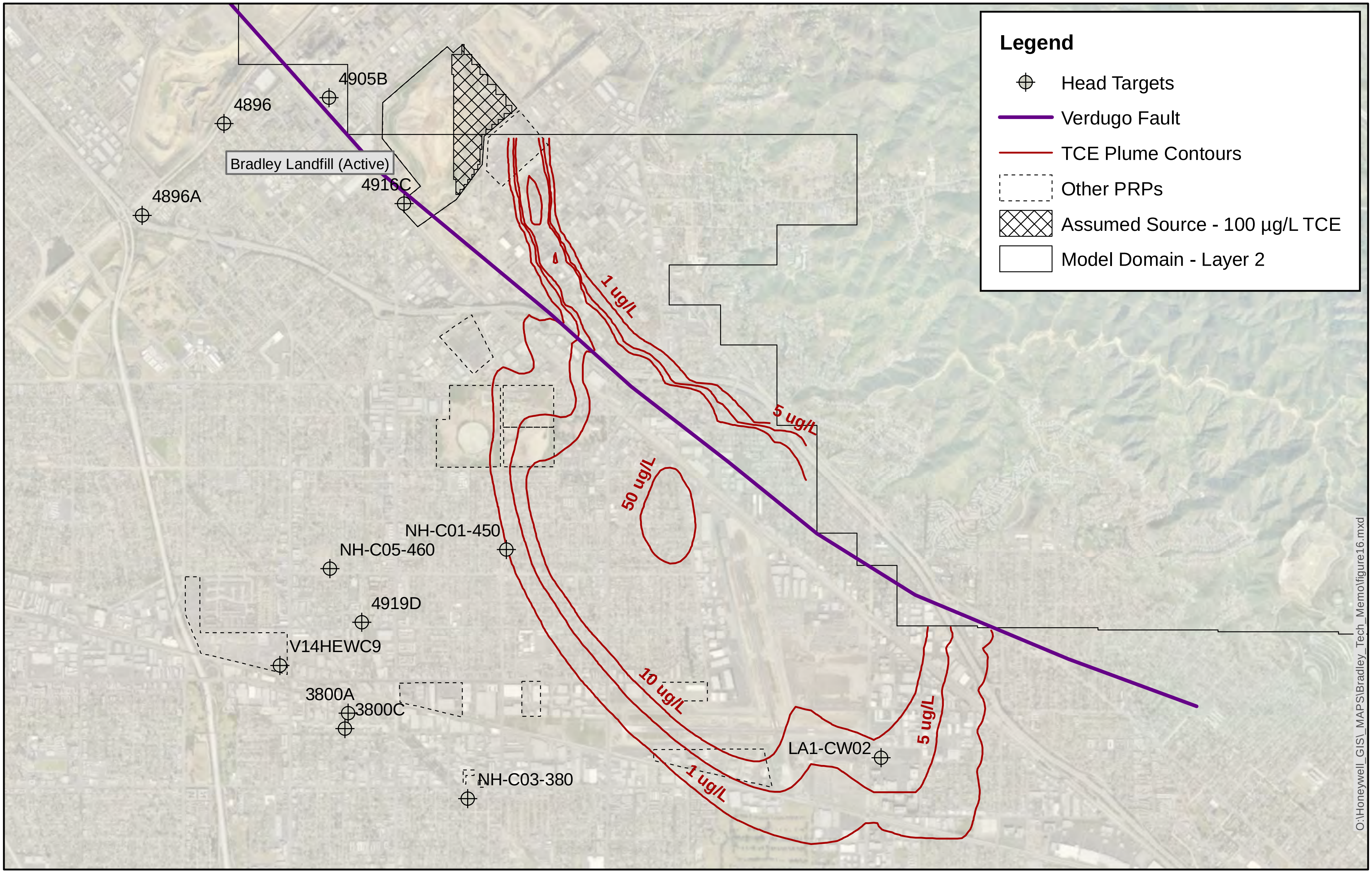


FIGURE 15

Simulated TCE Concentrations
Depth Region 1
Original Horizontal Conductivity Scenario



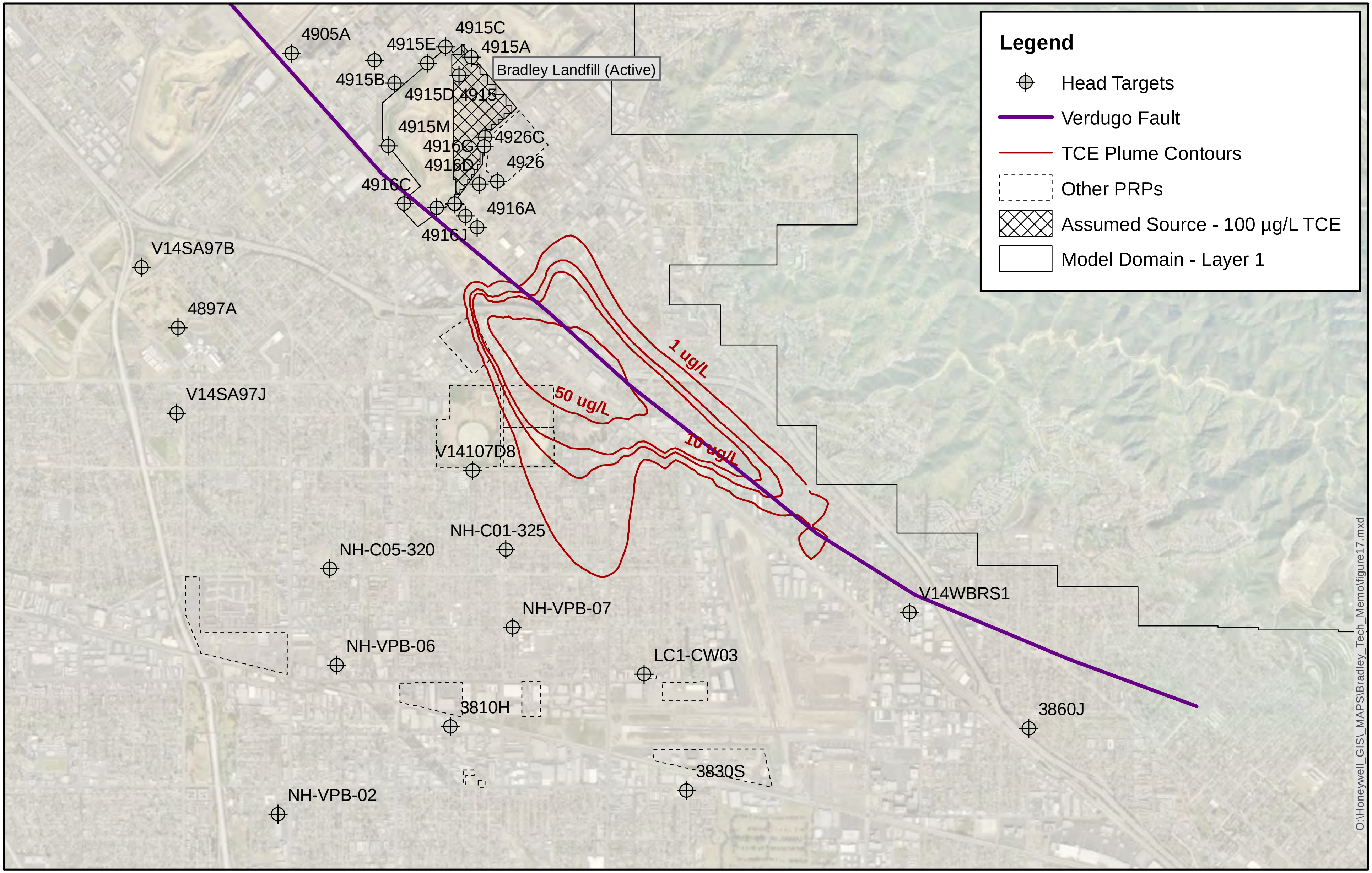
Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1968 to October 1984.

N

0 1,700 3,400 6,800 Feet

FIGURE 16

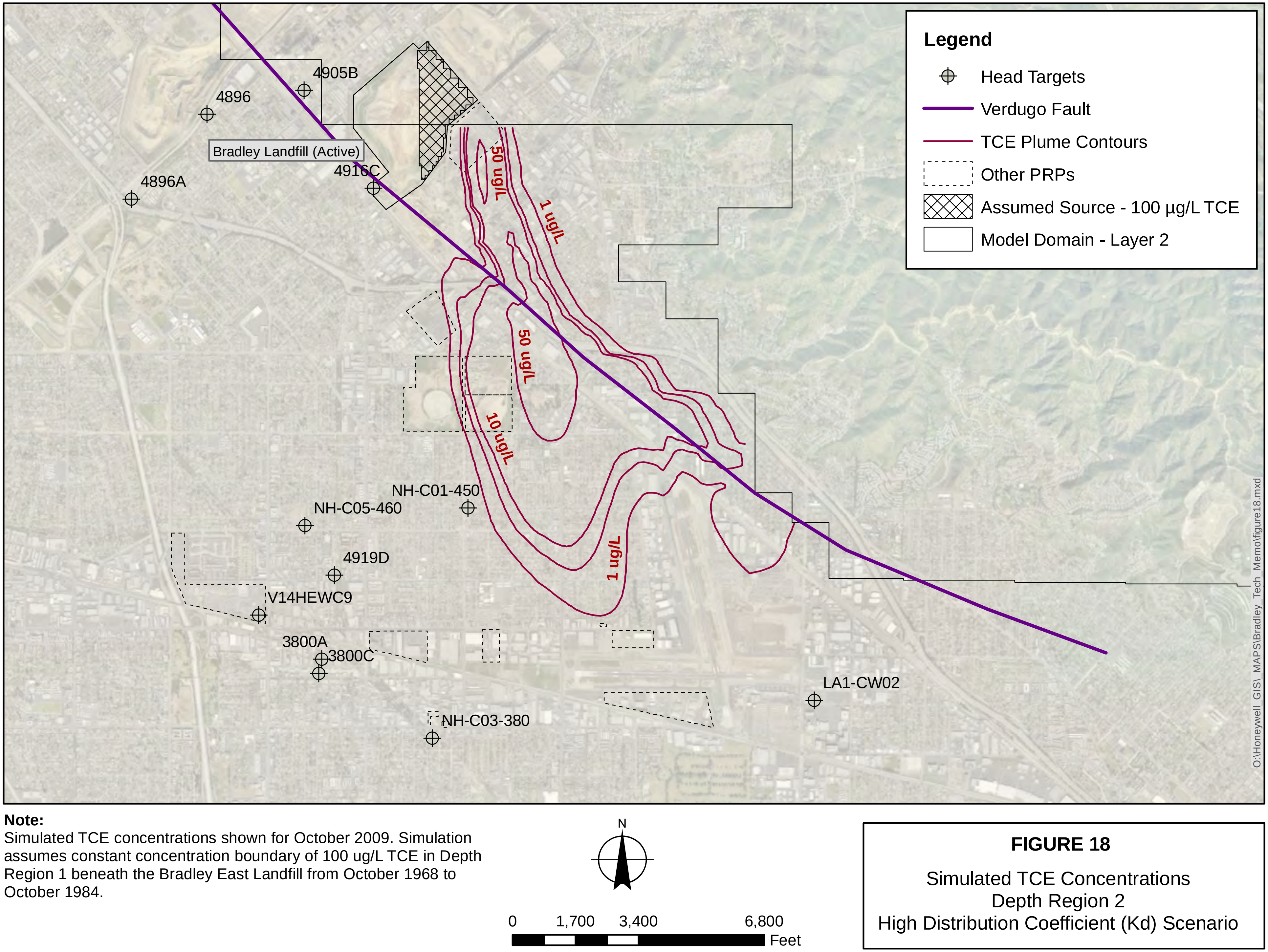
Simulated TCE Concentrations
Depth Region 2
Original Horizontal Conductivity Scenario



Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1968 to October 1984.

FIGURE 17

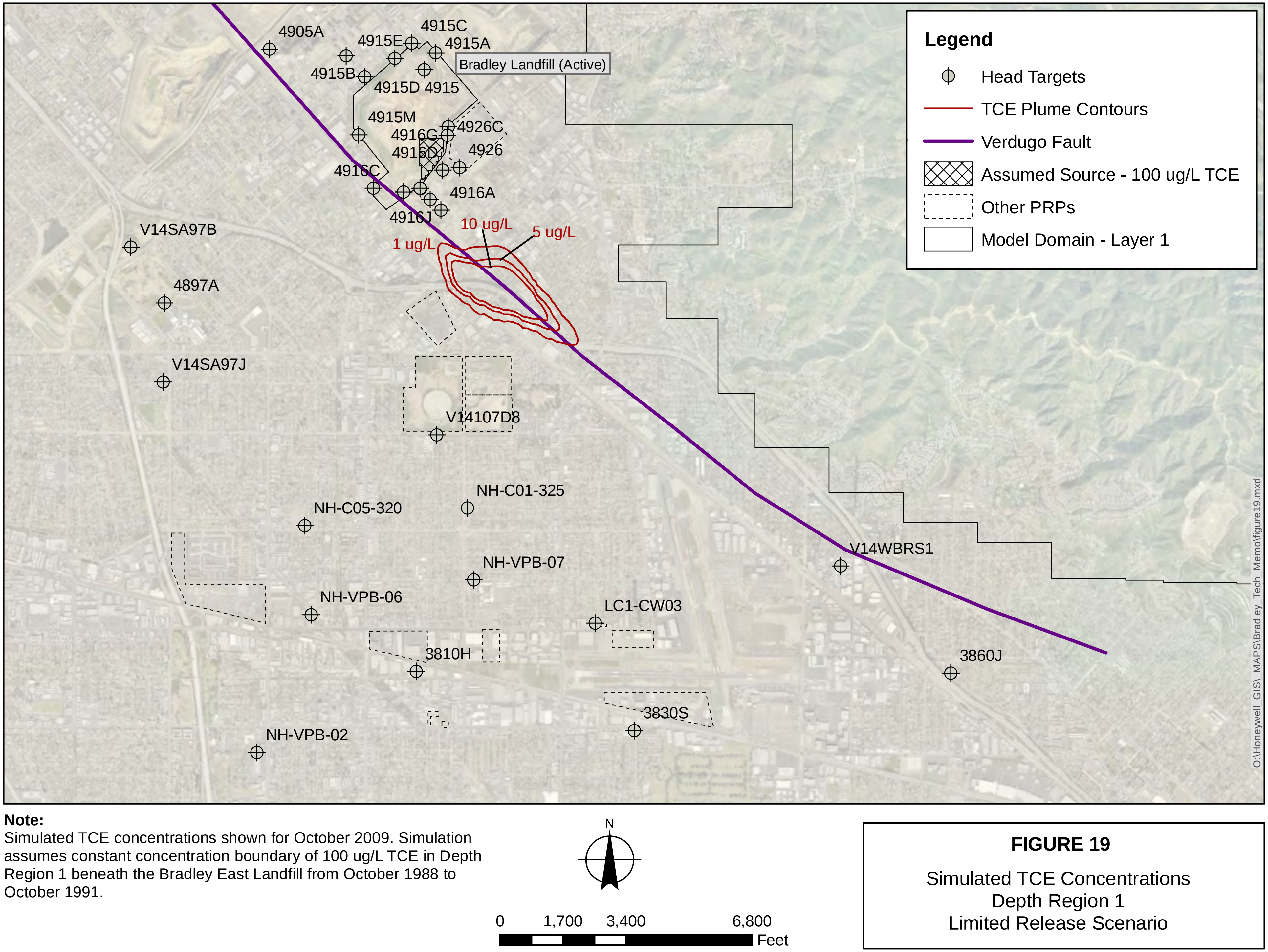
Simulated TCE Concentrations
Depth Region 1
High Distribution Coefficient (Kd) Scenario



Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1968 to October 1984.

FIGURE 18

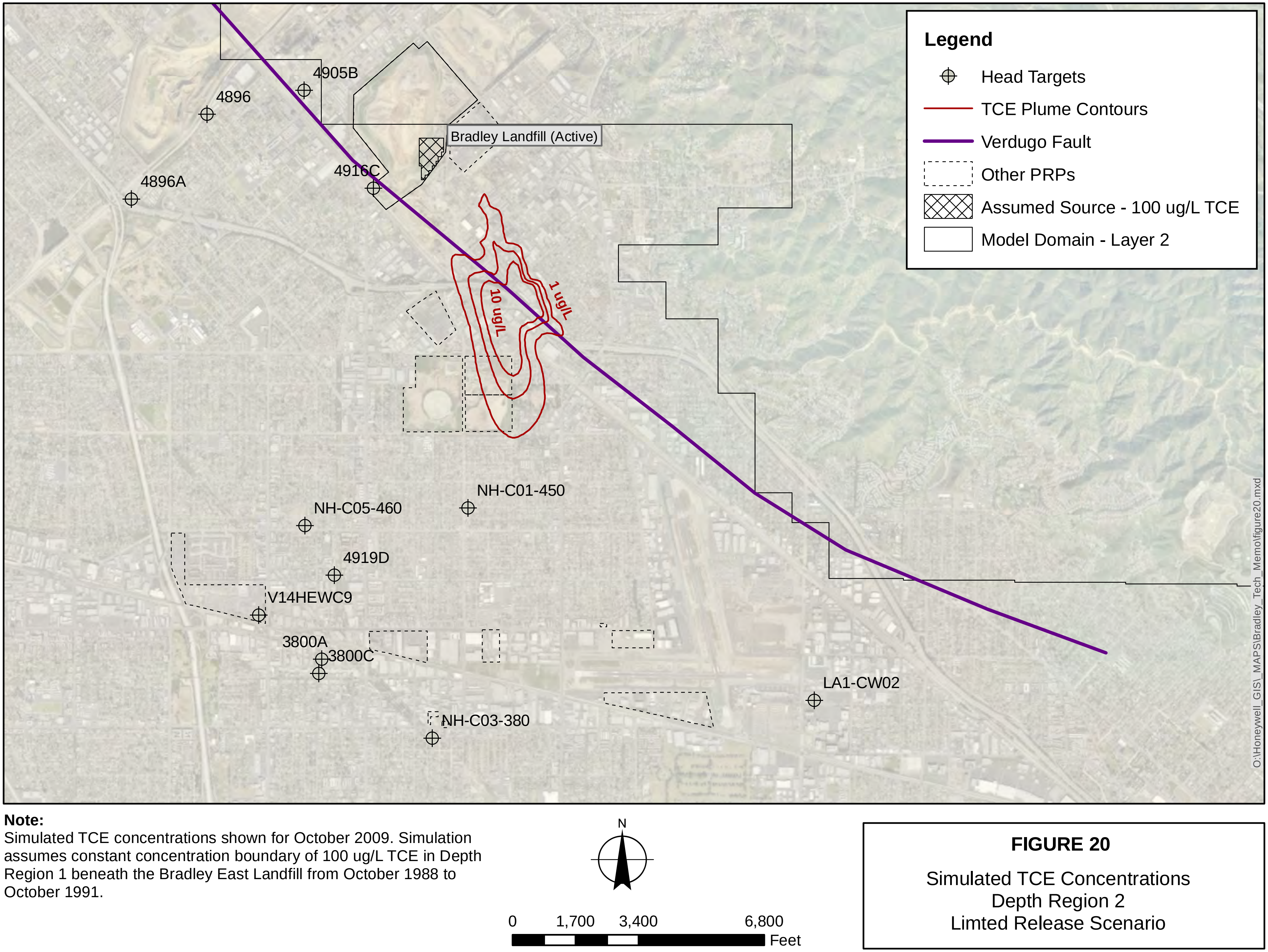
Simulated TCE Concentrations
Depth Region 2
High Distribution Coefficient (Kd) Scenario



Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1988 to October 1991.

FIGURE 19

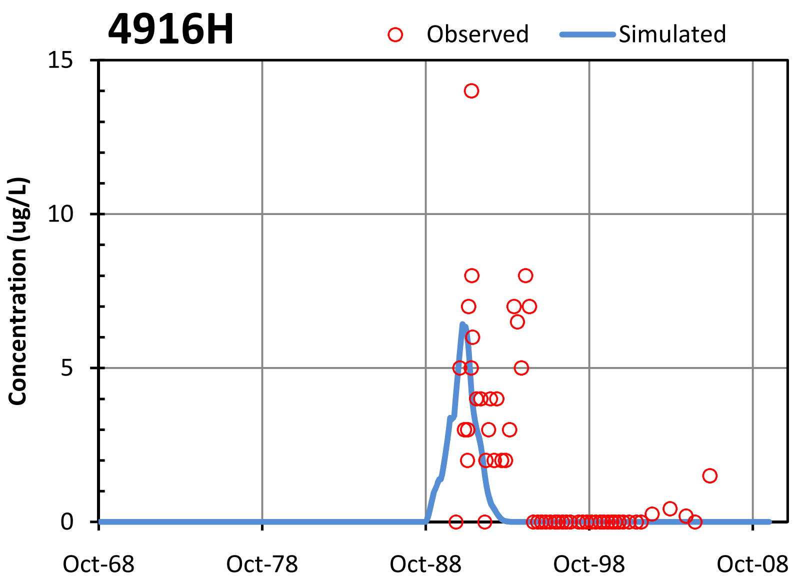
Simulated TCE Concentrations
Depth Region 1
Limited Release Scenario

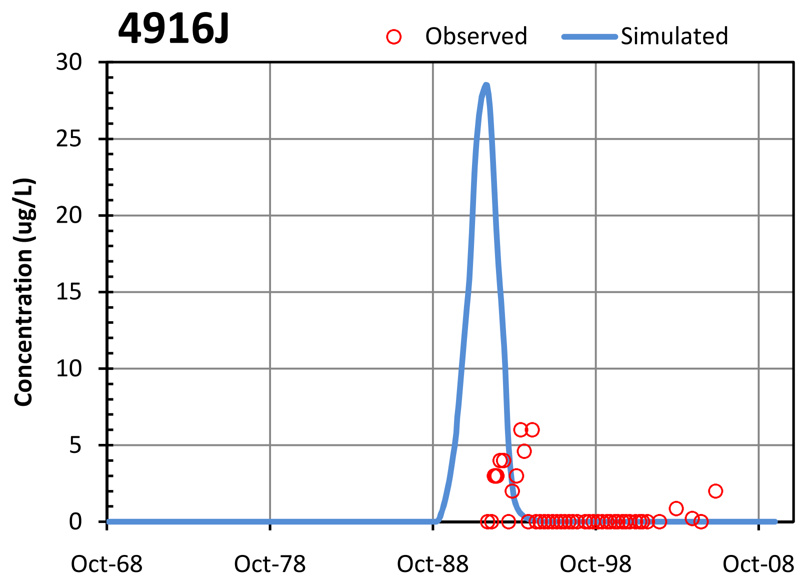


Note:
Simulated TCE concentrations shown for October 2009. Simulation assumes constant concentration boundary of 100 ug/L TCE in Depth Region 1 beneath the Bradley East Landfill from October 1988 to October 1991.

FIGURE 20

Simulated TCE Concentrations
Depth Region 2
Limted Release Scenario





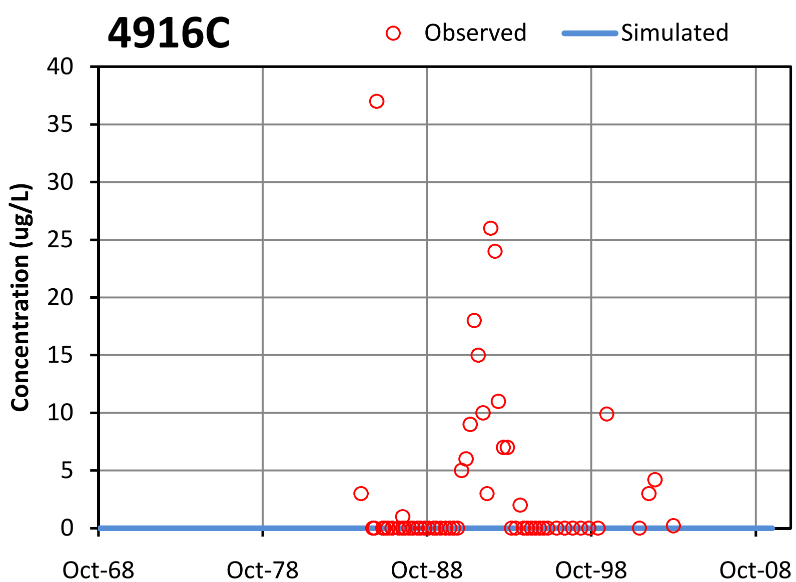


FIGURE 21

Simulated and Observed TCE Concentrations - Limited Source Scenario

TABLE 1
WELL SCREEN ELEVATIONS
BRADLEY LANDFILL AREA

Well Name	Original SFBFS-B Model			NHOU Database					Corresponding Model Layers for Revised Model
	Screen Top Elevation (ft msl)	Screen Bottom Elevation (ft msl)	Corresponding Model Layers	Well Top Elevation (ft msl)	Screen Top (ft bgs)	Screen Bottom (ft bgs)	Screen Top Elevation (ft msl)	Screen Bottom Elevation (ft msl)	
4916A	416.1	406.1	2	870	200 370 454	350 398 464	670 500 416	520 472 406	1,2
4916	423.9	214.9	2,3	863	155	364	708	499	1
4916B	502.2	450.2	2	712	159 260 271 346 356 374	239 262 280 350 366 382	553 452 441 366 356 338	473 450 432 362 346 330	1,2
4916D	480.9	374.1	1,2	882	220	325	662	557	1
4916x	457.9	350.1	2	NA	NA	NA			2

Notes:

ft bgs - feet below ground surface

ft msl - feet below mean sea level

NA - not available